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EFFECT OF DIFFERENT OXYGEN BARRIER POUCHES ON THE QUALITY OF RETORTED CARROTS

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EFFECT OF DIFFERENT OXYGEN BARRIER POUCHES ON THE QUALITY OF RETORTED CARROTS

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Accepted by:
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ABSTRACT

Thermally processed (TP) baby carrots were packaged in pouches with varying oxygen transmission rate (OTR) pouches. The pouches were four layer laminate (PET-Nylon-Barrier-CPP) with barrier layer being foil, aluminum oxide (AlOx), ethylene vinyl alcohol (EVOH), and nylon. Retort pouches were placed in boxes that were stored in an environmental chamber (43°C, 50%RH). The objective of the study was to determine an alternative barrier retort pouch that is microwavable and still had similar barrier functions to foil for baby carrots and determine how the alternative compare with regard to shelf life. Instrumental analysis of color (L*, a*, b*) and texture (firmness) was performed on TP baby carrots in the different oxygen barrier pouches. OTR of pouches were measured pre-, post- processing, and at week 14. Sensorial analysis was performed with frequent panelists. The results were correlated to determine if there was a relationship between instrumental measurements and sensory analysis of TP baby carrots packed in varying OTR pouches for color and texture.

Firmness of the retorted carrots did not change drastically over time, but showed some difference within each week. There was a weak correlation (R^2 = 0.2329) between instrumental texture measurement to sensory analysis. The instrumental color analysis showed a clear trend of split between foil and AlOx barrier materials with the other 2 materials starting week 6. Overall, TP baby carrots in EVOH and nylon pouches were significantly darker (decreasing L*), less red (decreasing a*), and less yellow (decreasing b*) than the carrots in foil and AlOx throughout the study after week 4. The higher OTR of EVOH and nylon allows more oxygen to go through the pouch; thus driving the

reaction that changes the color of carrots. Color of carrots in foil and AlOx were ranked significantly higher than the carrots in EVOH and nylon pouches for sensory.

Due to the high OTR of EVOH and nylon, the carrots had less liking and acceptability over time. These two barrier pouches did not provide adequate barrier for maximum shelf life when compared to foil and AlOx barrier pouches. The carrots in foil and AlOx had a predicted shelf life of at least 24.5 weeks or more; however, the carrots in EVOH and nylon only lasted half that time.

DEDICATION

This thesis is dedicated to my parents and family members who never stopped believing in me. I am a stronger person because of their support and never ending love that has helped me get through this.

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CHAPTER ONE

INTRODUCTION

Retort pouches are heat-resistant bags or pouches composed of multi-layer film. These pouches were first used to replace traditional metal cans used by the U.S. military MRE (meals ready to eat) program. Although the biggest user of retortable flexible pouches is the U.S. military, retort pouches are beginning to be used for packaging consumer foods in grocery stores. Retort pouches have some advantages over bottles and cans, thinner profile (thus taking up less space), higher ratio of surface area to volume, shorter processing time, higher quality food, lighter weight (save on shipping and cost of package). Furthermore, a retort pouch is easier to open and is more environmentally friendly (source/energy reduction).

Healthy foods are usually associated with vegetables and fruits. A lot of people get scared just hearing the word 'healthy'. In 2010, carrot farmers spent $25 million on an ad campaign to portray carrots as "cool" as junk food in order to boost sales. The idea behind this was to get kids to eat more of them if they could think of carrots as a kind of junk food. One way to get these carrots into hands of the teenagers was by placing them in school vending machines. This way the carrots can be put on even footing with the other packaged junk food (Aubrey 2010).

Carrots provide 30% of the vitamin A in the US diet (Simon 2004). Retorted carrots are one way to obtain vitamin A needed in our daily diet. Thus, anything that encourages consumes to eat more carrots improves the health of the public. The benefit of being shelf stable allows consumers to keep them readily available for approximately 3 years. Retorted baby carrots are currently only available in cans at the grocery stores. Making retorted baby carrots available in pouches would be beneficial to consumers due to the many advantages of flexible packaging; on top of having better quality baby carrots compared to cans.

The objectives of the following study were four fold:

1. To determine if there were alternative to the foil barrier that allow microwaveable reheating and still has sufficient barrier function.

2. To instrumentally measure the oxygen transmission rate of retort pouches and the qualitative attributes of texture and color of thermally processed baby carrots in different oxygen barrier pouches.

3. To quantify sensorial analysis of thermally processed baby carrots using frequent panelists.

4. To determine if a correlation exists between the instrumental (objective) and sensory (subjective) measurements of thermally processed baby carrots.

CHAPTER TWO

LITERATURE REVIEW

Baby Carrots

Daucus carota L. subsp. *sativus.* is the Latin name for carrots. Carrots are root vegetables that are usually orange in color; however, there are white, purple, red, and yellow carrots. Carrots first originated in Afghanistan and possibly northern Iran and Pakistan (Simon 2004). Orange color carrots originated from Europe and Middle East in the 1600s (Simon 2005). Today, in the United States, Bakersfield, CA is the home to the nation's top two carrot processors – Grimmway Farms and Bolthouse Farms (Carrotmuseum.com 2011). In the US diet, carrots provide 30% of the Vitamin A (Simon 2004). Jeanne Ambrose, food and entertainment editor at Better Homes and Gardens, states that the public has "pretty much adopted baby carrots as a snack food" (Weise 2004).

There has been confusion among people regarding what baby carrots really are. Baby carrots may either be "true" baby carrots or manufactured baby carrots. Carrots that are grown to the "baby stage" are known as the "true" baby carrots. In other words, it is harvested long before the root reaches its mature size. There are different cultivars of carrots that have been bred to the "baby" stage and one of them is 'Amsterdam Forcing'. These types of carrots, if carried in the stores, are usually very expensive, they are small, slender, and finger shaped carrots. Another type of cultivar is the Thumbelina, or Paris Market, that is shaped like a golf ball (Carrotmuseum.com 2011).

Manufactured baby carrots, on the other hand, are cut and peeled to the shape they are now. It was first invented in the late 1980s by a California carrot grower, Mike Yurosek, with the intention of making use of carrots that are too twisted or knobby for sale as full-size carrots. With the help of an industrial green bean cutter and an industrial potato peeler, he created the baby carrot (Carrotmuseum.com 2011). These are the baby carrots that are usually seen in stores which are packaged in bags.

The United States Department of Agriculture (USDA) Economic Research Service (ERS) published a report in 2008 regarding consumer perceptions and consumption of canned fruits and vegetables. "Canned" does not only refer to the traditional airtight shelf-stable metal cans but also refers to other newer and increasingly popular types of airtight containers such as jars and retort pouches. In 2006, consumer expenditures were estimated at \$6.4 billion for canned fruits and vegetables at supermarkets and mass supercenters. There was an increase in availability of canned vegetables by 5% between the year 1970 and 2005. The increase in awareness of nutritional benefits of fruits and vegetables may potentially increase the demand for canned fruits and vegetables. In 2005, vegetables by type of processing by farm weight per capita availability showed that fresh (197.1) was highest, followed by canning (105.5), freezing (75.0), and dried (14.1) (Buzby and others 2008).

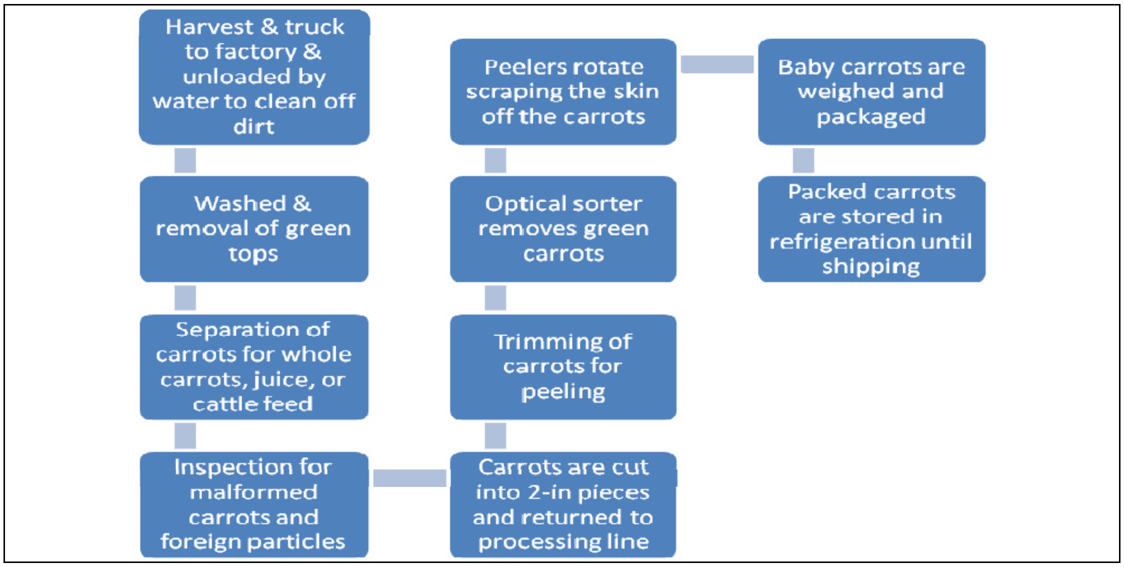


Figure 2.1: Flow Diagram of Baby Carrots Processing (GrimmwayFarms.com 2011)

The processing of baby carrots is shown in Figure 2.1. Baby carrots are usually cleaned using a chlorine rinse. There are regulations set by U.S. Food and Drug Administration in accordance with the Federal Food, Drug and Cosmetic that allow sanitizers to be used to wash fruits and vegetables. This is regulated in the Code of Federal Regulations, Title 21, Ch. 1, Section 173.315. Chlorine use as a sanitizer in wash, spray, and flume waters is common in fruits and vegetables washing in the industry (Beuchat and Ryu 1997).

Raw baby carrots are typically packaged in clear oriented polypropylene (OPP). Traditionally pillow style pouches have been used but a new development called a steady flat bottom pack with a 4 edge seal made by Ulma Packaging is also available (a company located in Spain); see Figure 2.2. Thermally processed carrots, typically packaged in cans that can be found in U.S. grocery stores include sliced carrots, julienne cut carrots, diced carrots, and whole baby carrots, see Figure 2.3.

Figure 2.2(L-R): Baby carrots packaged in OPP (GreenGiantFresh.com 2011); Baby carrots by Ulma Packaging (UlmaPackaging.com 2011)

Figure 2.3 (L-R): Del Monte's sliced carrots; S & W julienne carrots; ShopRite diced carrots; Le Sueur baby whole carrots (ShopRite.com 2011)

Fresh carrots are refrigerated to preserve their flavor and texture. They should not be stored together with fruits or vegetables that produce ethylene gas as they ripen. The exposure to ethylene gas will turn carrots bitter (GreenGiantFresh.com 2011). Carrots are considered to have moderate (20-40 mg CO_2 kg^{-1} h^{-1}) respiration rate (Roberson 2006).

Figure 2.4: New packaging of baby carrots designed to look like junk food

With the increasing need for healthy food, carrot farmers spent $25 million on an effort to make carrots seem as “cool” as junk food in order to boost sales. Packages such as those seen in Figure 2.4 were introduced in school vending machine to capture the kids’ attention in hopes that they may purchase it (Aubrey 2010).

Aside from fresh produce, canned products are the next highest type of processing that is available in the market. Making retorted baby carrots available in pouches would be beneficial to consumers due to the many advantages of flexible packaging; as well as having better quality baby carrots compared to cans. The process of retorting and advantages of flexible packaging will be discussed further in this chapter.

Thermal Processing

Thermal processing is considered a part of the wider field of industrial sterilization which includes not only food processing but also medical and pharmaceutical processing (Holdsworth and Simpson 2008). Inactivation of microorganisms by heat is a fundamental operation in food preservation. According to the Code of Federal Regulations (9 CFR 318.300), thermal processing is determined by a processing authority. Thermal processing is the use of heat treatment, in terms of time and temperature as well as minimum product temperature as determined by the processing authority (Code of Federal Regulations 2010). The purpose of thermal processing is to achieve shelf stability.

Thermal processing is achieved by variety of mechanisms, one of which is a retort. A retort is a chamber in which high temperatures and pressure can be used to achieve commercial sterility in food product. Commercial sterility results in shelf stability and is achieve by the application of heat, either alone or with other ingredients and/or treatment, to produce a product that is non-refrigerated and free of pathogenic (those that cause food borne illness) microorganisms (USDA FSIS 2005). The process not only extends the shelf life, it affects the nutritional values and quality of the product (Al-Baali and Farid 2006). Food products that are commercially sterile, canned and bottled, is commonly expected to have a shelf life of 2 years or more. Over time, deterioration usually is due to texture, nutritional loss, or flavor changes and not so much due to microbial spoilage (Potter and Hotchkiss 1998).

The success of retorting is not only dependent on the ability to inactivate microorganisms but also on other factors (nature of the food-pH, environment-vacuum, hermetic storage, and storage temperatures) that may be associated with the inactivation of spoilage and pathogenic microorganisms (Ahmed and Shivhare 2006). Products that require retorting at temperatures above 212°F have characteristics such as low acid ($pH>4.6$) and high water activity ($a_w>0.85$). Low-acid foods include red meats, seafood, poultry, milk, and all fresh vegetables except for most tomatoes (USDA 2011). Thermal processing of low-acid canned food (pH greater than 4.6, a_w greater than 0.85) focuses on the destruction of the spore forming bacteria (mainly *Clostridium botulinum*) (USDA FSIS 2005). These spores are difficult to destroy and products of concern with this type of spores should be sterilized at 240-250°F (USDA 2011).

On the other hand, high-acid foods naturally have a pH of 4.6 or lower. Examples of these types of foods are fruits, jams, and jellies. Typically, these products are hot filled. These foods have enough acid in them to block the growth of bacteria or to destroy bacteria more rapidly when heated. High acid foods may be processed at boiling water temperatures (212°F) (USDA 2011). Acidified food is product that is treated to ensure that every component of the finished product has a pH of 4.6 or lower within 24 hours (or however long is determined by processing authority) after the completion of thermal processing (Code of Federal Regulations 2010). Acidified foods do not require high temperature processing (212°F or lower). This temperature processing is sufficient to destroy vegetative cells and some spores of low heat resistance. The low pH prevents the remaining spores from growing out (USDA FSIS 2005).

There are different retort types that are available, see Figure 2.5. Batch retorts are more flexible compared to continuous retorts especially if the batch retorts have the capability for overpressure throughout the heating and cooling process. Overpressure is necessary to minimize pack damage (May 2001). As a package is undergoing retort processing, heat expansion in the package occurs and there is a pressure differential between the retort and the inside of the package. These stresses can cause damage to the package. Package damage includes loss of seal integrity and stress cracks or pinholes. Overpressure created by the retort prevents pack damage by reducing package expansion.

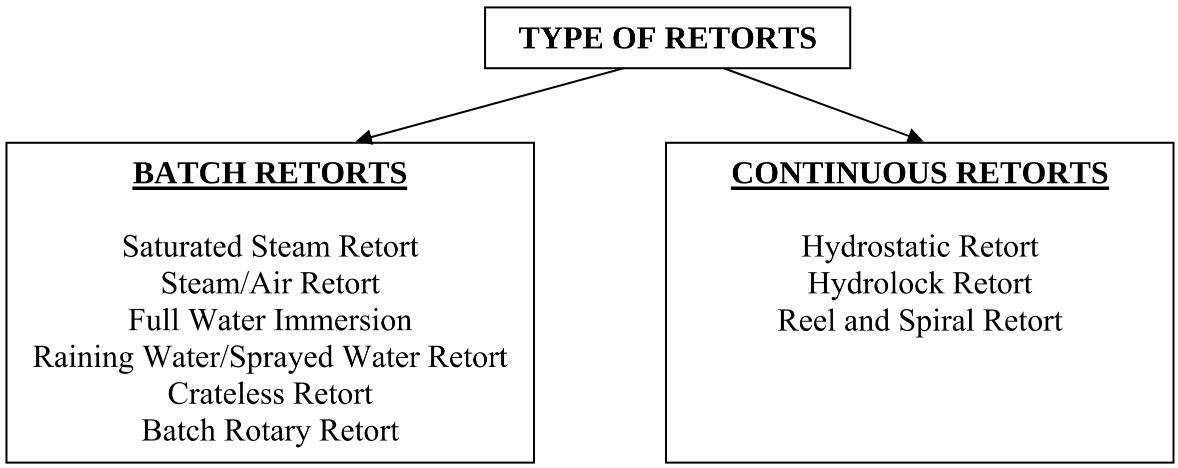


Figure 2.5 Types of Retort (May 2001)

Process Determination

In order to maximize the benefit of thermal processing without compromising the quality of the product, the use of good mathematical modeling is essential (Ahmed and Shivhare 2006). However, even with the least amount of heating, thermal processing can promote reactions that could affect the overall quality of food (Awuah and others 2007). One important factor in the design of thermal food process operation that needs to be noted prior to processing is the slowest heating zone during the process, which may often be referred to as the thermal center of the food.

The rate of heat penetration is measured through the use of thermocouples inserted at the center of the product in the container to record the temperature of the food during thermal processing. This is with the assumption that all other points in the container receive more heat and therefore is considered adequately processed (Al-Baali and Farid 2006). The objective of a heat penetration study is to study the heating and cooling behavior of the product prior to processing to determine the thermal process as well as to have data available for future process deviation. For example, if someone wanted to process a similar product, that the data may be useful to determine a thermal process. There is a requirement of ten samples in two replicate runs that has to be met. In addition to that, the heat penetration study should be done based on the worst case scenario (Tucker 2001). The worst case scenario includes higher fill weights and increased residual gas in a normal package; with the thermocouples at the slowest heating region of the package.

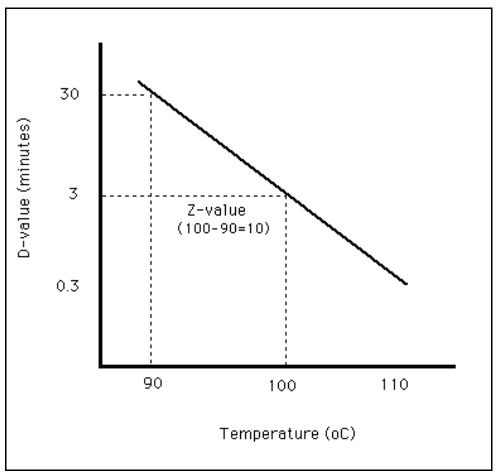


Figure 2.6: Thermal Death Curve (Goff 2011)

Thermal destruction of microorganisms is logarithmic meaning a 10-fold decrease for every 10°C increase. A death rate curve of a microbial population is a plot of microbial spore population versus time on semi-logarithmic coordinates. This relationship will provide the decimal reduction time (D_T). D_T is the time that is required to kill 90% of the microorganisms (the reduction of number of microorganisms by a factor of 10, one-log cycle reduction). The plotting of decimal reduction time versus temperature on semi-logarithmic coordinates yields a linear relationship (thermal death time curve for the given microbial population). An example is shown in Figure 2.6. The slope of the curve, known as the Z value, is referred to as the temperature increase that is required for a one-log cycle reduction of the decimal reduction time. These two parameters are correlated in this way because the destruction of microorganisms is temperature dependant. As the temperature increases, the D_T value decreases (Al-Baali and Farid 2006).

Another important parameter that is of concern during thermal processing is the thermal death time (F), or F value. This is the time that is required to destroy a certain amount of microorganisms at a specified temperature and Z value. It is the total time-temperature combination received by a product. The suffixes indicate the retort temperature and the Z value of the target microorganism. F value is defined through the following equation:

$$F^{Z}_{Tref} = D_{Tref} (\log n_1 - \log n_2)$$

T_{ref} = arbitrary reference temperature

n_1 = initial concentration of microorganisms at the start of thermal processing

n_2 = final concentration of microorganisms at the end of thermal processing

An example described by Al-Baali and Farid shows that the initial concentration of *C.botulinum* is usually set to be below 10^{12} spores per milliliter; and the final concentration after processing at 121°C is less than 1 spore per milliliter. Thus, with a D_{121} value of 0.1 to 0.2 minutes and a Z value of 10°C.

$$F = 0.1*10 (\log 10^{12} - \log 1) = 12D$$

Retort Pouch

Meal, Combat, Individual (MCI) also known as the "C" ration was composed of canned foods. MCI was first developed during the World War II and it has contributed much to today's grocery shelves product. The MCI was replaced with the Meal, Ready-to-Eat (MRE). These meals have been investigated since 1950s by the Armed Forces at the U.S. Army Natick Research and Development Laboratories (Tuomy and Young 1982). The retort pouch earned the Food Technologists' 1978 Food Technology Industrial Achievement Award (Mermelstein 1978). The retort pouch is a fast-growing packaging technology in today's consumer world, replacing canned products. The pouch first made it to the consumer level with Mars Inc. launching the "Kal-Kan's Whiskas" cat food in May 1999. In June 2000, StarKist announced the launching of "StarKist Tuna" in a pouch (Flexnews.com 2007).

The basic definition of a retort pouch is a heat-resistant bag or pouch that is comprised of laminated plastic films or foils. The pouches are then filled, heat-sealed and sterilized through high temperature processing. The thermal processing occurs under pressure in a retort to produce commercially sterilized food (Flexnews.com 2007). The purpose of retort pouches is to provide a shelf stable, low acid, high water activity foods, but of a higher quality compared to food processed in cans (Brody 2003). There are certain requirements of films used for the retort pouch, including low oxygen and water permeability, temperature stability from 0-150°C, heat sealability, suitability for use with food, dimensional stability, good physical and seal strength, and appropriate regulatory status (Subramanian and others 1986).

Shelf life of foods that are packaged in retort pouches depends on the storage temperature. For example, when stored at 16°C, the product will last for about 130 months. With an increase of about 10°C, the shelf life is shortened to 76 months; and 22 months when it is stored at another increase of 10°C. For this reason, military MRE's are stored in climate controlled warehouse when possible to ensure the rations could be kept for up to 10 years (Robertson 2006). The most common structure of retortable pouch is made from a laminate of three materials as shown in Figure 2.7.

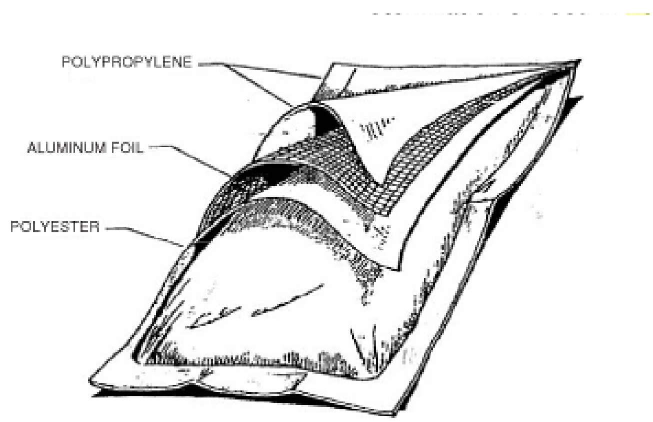


Figure 2.7: Retort Pouch Structure (Lampi 1980)

Table 2.1: Typical Retort Pouch Structure and Functionality

Structure (Layer)	**Function**
Outer layer: 12μm Polyester film	High temperature resistance, toughness, and printability
Middle layer: 9-18μm Barrier (Aluminum foil) film	Moisture, light, and gas barrier
Inner layer: 76μm Polypropylene film	Heat seal and food-contact material

* In between each layer is adhesive to bind the layers together

According to Aaron L. Brody, in recent years, aluminum foil has been replaced to some degree by silica or glass coating. This is to increase the product visibility as well as microwavability (Flexnews.com 2007). An additional nylon layer may be added either between the outer and middle layer or between the middle and inner layer to increase strength of the pouch.

There are many advantages of retort pouches compared to cans or to frozen food packaging for the food processor, distributor, retailer, and consumer. The retortable pouch combines the advantages of metal cans and plastic containers. The retort pouch has a thinner profile as well as a larger surface area per unit volume thus enabling less processing time (takes less time to achieve sterilization conditions) when compared to the cans or jars. With short processing time, the quality of the product is better maintained. This reduction in processing time enables the product to maintain its color, texture, freshness, and nutrient levels. Short processing time also is more energy efficient. The retort pouch requires less energy to manufacture. The total energy required from harvest to consumption is about 60% lower for vegetables that are packaged in a retort pouch than in a frozen package and it is 15% lower for the canned vegetables (Mermelstein 1978).

Retort pouches do not need to be refrigerated or frozen and are shelf stable at room temperature. The product is ready to be eaten even without heating or could be heated easily/quickly. The frozen product, on the other hand, requires a longer time to heat. Compared to a metal cans, there are no sharp edges to a retort pouch; therefore, reducing the possibilities of cuts. In addition to that, the ability to easily tear across the top notch of pouches eliminates the use of can openers. The flat retort pouch profile takes up less space, both in shipping and storage, whether filled or empty. Pouches weigh less and have a thin profile compared to cans and glasses, thus lowering transportation and storage cost (Mermelstein 1978).

When comparing the retort pouch to cans, with the same fill size, the retort pouch label display area is greater. The profile of the pouch enables package differentiation and larger shelf display, therefore increasing opportunity for sales. Retort pouches have better durability compared to the cans because there will not be dented cans (Mykytiuk 2002). Disposal of retort pouches takes up less disposal space than other types of food packaging. The costs are also less for refuse removal and incineration of retort pouches (Mermelstein 1978). With all the benefits of the retort pouches, it is ideal not only for military use, but also for grocery consumer use.

Materials

When thermally processing, a couple of key requirements of packaging materials are the oxygen and water vapor barriers. These requirements are important for the pouch during processing as well as for the duration of the shelf life of the product (Bull and others 2010). Oxygen barrier is required because many products are sensitive to oxygen especially in combination with the presence of light and heat. Fats and oils that are exposed to oxygen causes rancidity (flavor changes); color changes are also affected by presence of oxygen. The water vapor barrier is necessary to maintain freshness, wholesomeness, and appeal of food. Quality of food may be affected if the water content exceeds certain limits with the transfer of water into or out of the food product (Brown 1992).

Material Properties

Mermelstein interviewed Jerry Darsch (Director of the U.S. Dept. of Defense's Combat Feeding Program in the Soldier Systems Centers, previously known as Natick Labs) in regards to military and humanitarian rations. Darsch mentioned that prior to the four layer MRE pouch, trilaminate materials were used to make the retort pouch for the entrees. It is now a four layer pouch – polypropylene that is associated with food-contact surface, aluminum foil, nylon, and polyester. Nylon was added to increase the performance capability on the battlefield, and that increase layer had no significant cost or weight increase (Mermelstein 2001).

A typical three-layer pouch structure could consist of an outer layer of PET for strength, toughness, and temperature resistance, a middle layer of aluminum foil as the barrier layer (for moisture, light, and gas barrier), and an inner layer of CPP for heat sealability, strength, and compatibility with foods. The addition of polyamide (PA or better known as nylon) is used when desiring a longer shelf life, in addition to providing extra strength for the retort pouch. For microwaveability, the foil barrier can be replaced with other materials. These typical structures include PET-OPA-CPP, SiO_x PET-OPA-CPP, AlO_x PET-OPA-CPP, OPA-PVdC-CPP, and OPA-EVOH-CPP (Robertson 2006).

Heat sealing is a process by which two structures containing at least one thermoplastic layer is sealed by heat and pressure (Selke and others 2004). The strength properties of a pouch material refer to its tensile strength and the seal strength. In order to have good strength in the seal area and to reduce the risk of seal defects, a double sealing of 5-10mm per sealing area is desired (Juliano and others 2010). It is a significant problem when hermatically sealed pouches are desired and wrinkles are seen. Contamination of the seal area can also affect the seal strength and package integrity. Polypropylene (PP) is usually used as a sealant layer in retort packaging (Selke and others 2004).

Aluminum foil is a thin-rolled sheet of alloyed aluminum that is essentially impermeable to gases and water vapor (Robertson 2006). For use in flexible packaging, alloys commonly chosen are 1145 and 1100 foils (Hirsch 1991). Aluminum foil plays a prominent role in modern food packaging. The barrier effect, dead fold, and food contact ability enables the material to be used for a wide range of applications in many different products, not just in food packaging. Foil can be applied as an uncoated metal or in combination with other materials. Thickness of the aluminum layer determines the classification of aluminum foil laminate packages. For flexible packages, the thickness of the aluminum layer is between 9 and 50 µm (Lamberti and Escher 2007). Bare foil 25.4 µm and thicker is completely impermeable and thinner gauges laminated to certain materials can produce impervious composite materials (The Aluminum Association, Inc. 2004).

One important property of aluminum foil in the packaging of food is the barrier function against the ingress of oxygen, water vapor, light, flavor compounds, microorganisms, and grease. However, thin layers of aluminum foil within laminates are susceptible to flex cracking at stress points that affect the barrier properties of the material (Lamberti and Escher 2007). A study done by Chandrasekar and others showed that the retort pouch that was used (outer polyester layer, middle aluminum layer, inner cast polypropylene layer) withstood the processing temperature (121°C) and pressure (28psi). There was no sign of delamination, leakage or spoilage to the product and was acceptable after 12 months of storage at ambient conditions (Chandrasekar and others 2004).

The study of ready-to-eat mussel meat processed in a three-layer retort pouch (PE/aluminum foil/CPP) with a thermal death time (F_o) value of 9.8 and cook value of 90 minutes remained in good condition after a year of storage at room temperature. This was determined by taste panels (Bindu and others 2004). Foil and AlOx barrier pouches containing salmon showed better shelf stability compared to cast polypropylene (CPP) that has poor oxygen barrier properties. The pouches were thermally processed and stored in the environmental chamber. A sensory study was conducted on the salmon and showed similarity between foil and AlOx containing salmon (Byun and others 2010).

Foil, as a barrier layer first starts off as a sheet and then evolves into a vacuum-deposited coating (metallization). An aluminum foil layer provides virtually a total barrier. A metalized layer may give almost as high barrier as the foil at a lower cost (Lange and Wyser 2003). Aluminum particles are vaporized in a closed chamber under high vacuum and condense on the film (Selka and others 2004). One of the functions of foil is its opacity (it will transmit no light) (The Aluminum Association, Inc. 2004). However, clear packaging films, offer the advantage of the ability to allow the customer to see the actual product before purchasing. Aluminum oxide is a coating that is transparent, yet provides oxygen and water vapor barriers comparable to foil, metalized films. This barrier is an excellent alternative to PVDC-coated films and Ethylene-Vinyl Alcohol (EVOH) laminations (Holovach 2009).

Toray Plastics (America), Inc. produces aluminum oxide transparent high-barrier film, Barrialox 1101 EG-C2 that is suitable for retort, boil, and microwave application. This material is a FDA-compliant film. A protective coating is applied on the aluminum oxide layer to give the oxide layer a better protection from scuffing and abrasions. The company ran a retort test on the aluminum oxide film laminated to a CPP using Morton AD503/CAT-10 adhesive. Pouches were filled with water and retorted at 120°C for 30minutes. The oxygen transmission rate (OTR) tested before and after retorting, showed that there was a slight increase in the permeation rate. The OTR prior to retorting was 0.0129 cc/100sq.in./day at 20°C, 0% RH and increased to 0.0257 cc/100sq.in./day at 20°C, 0%RH (Holovach 2009).

Ethylene vinyl alcohol (EVOH) copolymer was first commercialized by Kuraray Company, Japan in 1972. It was then commercialized in the U.S. and Europe in the early 1980s (Robertson 2006). EVOH often is used as a barrier layer in laminates for thermal processing (Lamberti and Escher 2007). EVOH has excellent processability as well as barrier properties. The barrier properties are for gases, odors, fragrances and solvents. These characteristics allow the replacement of glass and metal containers with plastic containers (Robertson 2006). The addition of EVOH in the packaging structure delays the ingress of oxygen, thus is important to maintain food quality and safety (López-Rubio and others 2005).

EVOH lacks water barrier when used alone. Therefore, in order to have an effective high oxygen barrier, EVOH has to be embedded within waterproof layer such as PP (Lamberti and Escher 2007). Packages with EVOH barriers with low ethylene contents do show a morphological deterioration as a result of retorting. Polymer morphology and barrier properties were restored after a dry thermal treatment. The study showed that after sterilization, the absorbed water is slowly eliminated from the copolymer structure as seen in the results of decreasing permeability with time (López-Rubio and others 2005).

Application of high temperatures during sterilization decreases the barrier properties of PP to water vapor. The increase in water uptake of EVOH increases the permeability to oxygen. If sterilization temperature is too high, the barrier layer may not recover due to the "retort shock" (Lamberti and Escher 2007). Mokwena and others studied the OTR of multilayer EVOH films after microwave sterilization; there was an increase in OTR in the film material after thermal processing. It is showed that during the first 2 month of storage, the multilayer EVOH films recovered to a certain degree and stabilized or increased during 12 months in storage (Mokwena and others 2009).

Nylon is a generic name for long-chain polyamide engineering thermoplastics and is generally a clear plastic (Massey 2003). It is thermoformable, strong, and tough over a broad range of temperatures. Nylon has good chemical resistance and is a good barrier to gas, oil, and aromas. This material is used in film form either as a single component or in multi-layer structures when it comes to packaging application. Nylons have good puncture resistance, impact strength, and temperature stability (Selke and others 2004).

Although nylon functions as a barrier, it is hygroscopic. This material is moisture sensitive and when left in normal environment conditions it can absorb 6-8% of its weight of water (Selke and others 2004). It is often combined with moisture barrier materials to achieve optimum gas and water protection (Massey 2003). When a study was conducted to determine the effect of pasteurization, high-pressure processing, and retorting have on the barrier properties of nylon 6, nylon 6/EVOH, and nylon 6/nanocomposites films; the nylon6/EVOH held up better during pasteurization and high-pressure processing compared to retort processing. The nylon 6/nanocomposites films were the best option used for retort conditions (Halim and others 2009).

EVOH and nylon contain polar groups and hydrogen bonding capability. They strongly absorb water from humid air. The presence of water vapor changes the permeation of other gases and vapors through the polymer. The water molecule acts as a plasticizer, which increases the free volume of the polymer. Therefore, in most cases, the permeation rate of these two materials increases with higher water sorption (Selke and others 2004).

Retort Pouch Production

Barrier layers can be included in a package through either lamination, co-extrusion or coating. Lamination is the production of multilayer flexible structures. Extrusion coating and lamination are operations that are closely related because of the equipment that are used in each of the operation are the same. Extrusion coating is the application of coating onto a web; whereas extrusion lamination is having a second web combined to the extrusion coated web with adhesives (Selke and others 2004).

The use of form-fill-seal (FFS) machines is most commonly used to make pouches. Pre-printed roll stock is formed into a package and the package is filled and sealed with product (all with the FFS machine). Aside from the FFS machine, preformed pouches can be used, where the premade pouch is supplied and is ready to be filled with product and the top seal is made. Retort pouches are not easy to seal. Wrinkling in the seal area should be eliminated to ensure sterility is achieved. It is difficult in itself to work with PP as the sealant layer on retort pouches. Therefore, most operations that use retort pouches prefer to buy preformed pouches rather than use an FFS system. This ensures that all but the final seal is made by the expert in the industry (Selke and others 2004).

Permeation

Permeability is usually associated with the quantitative evaluation of the barrier properties of materials. Lower permeability generally means better barrier of a material. Permeability is affected by various factors and that include polymer characteristics, permeant, and environment (Temperature, Humidity, and Pressure) (Massey 2003). The permeability or transmission rate of gases or vapors through materials is dependent on the solubility of gas or vapor and the rate of diffusion through the barrier.

Permeation rate is dependent on temperature as well as humidity. Therefore, permeation testing is often done in similar environmental conditions that the package will experience (Hirsch 1991). In addition, permeation testing is something done at retort conditions to ensure that the permeability of material upon processing is determined. Measuring the oxygen transmission rate (OTR) through the walls of a package is important. This enables better understanding of the materials before selection of flexible pouch materials. The increase in temperature and humidity increases the permeability of material. Molecules of polymers have more energy when heated and move more easily, creating more space for permeants to move through the material. Hygroscopic materials such as nylon and EVOH are greatly affected by humidity. Hydroxyl groups (-OH) cause materials such as nylon and EVOH permeability to be affected (Cooksey 2004).

The American Society for Testing of Materials (ASTM) method is most common in the United States to measure permeability of plastic materials. The two ASTM standards are ASTM D1434 and ASTM D3985. ASTM D3985 is the standard test method for oxygen gas transmission rate through plastic film and sheeting using a coulometric sensor; whereas ASTM D1434 is the standard test method for determining gas permeability characteristics of plastics film and sheeting (Massey 2003). The ASTM D3985 method is also known as the concentration increase method and this is the more commonly used method. The concentration increase method is done with the start of having one side with test gas, and maintaining the other side with inert gas to which the test gas diffuses to. The concentration of diffusing gas is measured to determine the permeability of the material (Robertson 2006).

Calculation of permeability of multilayer materials can be done with the following equation provided knowledge of the individual thicknesses and permeability coefficients of each layer. The permeability coefficient (P) is defined as the product of diffusion coefficient (D) and solubility coefficient (S) (Langowski 2008). The equation is also only applicable when the permeability coefficient is independent of pressure (Robertson 2006).

$$\text{Permeability coefficient (P)} = \text{Diffusivity (D)} * \text{Solubility (S)}$$

$$P_T = X_T / [(X_1/P_1) + (X_2/P_2) + (X_3/P_3)]$$

$$X = \text{thickness of the layer}$$

$$P = \text{permeability coefficient}$$

Studies done by Bull and others showed that pouches containing an aluminum foil barrier layer had the lowest OTRs of all materials, such as vapor-deposited silicon oxide and aluminum oxide (SiOx and AlOx), oriented nylon/polyamide (ON/OPA), and PVDC-methyl acrylate (PVDE-MA) before and after high pressure thermal processing (Bull and others 2010). EVOH films showed low oxygen and water permeability at low relative humidity (RH) at varying temperatures. This humidity dependence is due to interactions between small water molecules and the polymeric matrix. An increase in RH to above 75% showed a considerable increase in permeability (Zhang and others 2001).

High pressure processing affects the permeability of film structures of PET/Al_2O_3/PE and PP/nylon/PP. However, the oxygen permeance for PE/nylon/EVOH/PE and PE/nylon/PE were statistically not affected by high pressure processing. The comparison of eight film materials by Caner and others showed that the lowest permeance values were seen in films with SiO_X, PVDC, Al_2O_3, and EVOH (Caner and others 2000).

Table 2.2: Oxygen Permeability of EVOH and nylon (Strupinsky and Brody 2011)

Polymer / Material	**Oxygen Permeability at 73°F (cc*mil) / (100in^2*day*atm)**
Ethylene vinyl alcohol (EVOH), dry	0.01
Ethylene vinyl alcohol (EVOH), coex	0.04 to 0.07
MXD6 nylon, dry	0.15
MXD6 nylon, coex	0.25
Nylon 6 or 66, dry	1.5
Nylon 6 or 66, wet	7.0

*Coex - Coextruded

Texture Measurement

Texture is difficult to define due to the fact that it is different for each individual. According to the New Oxford American Dictionary, texture is defined as the feel, appearance, or consistency of a surface or a substance (Stevenson and Lindberg 2010). Texture is also defined as the property of food which is correlated to sense of feel or touch experienced by fingers or the mouth (Ranganna 1986).

Texture is often the attribute that is overlooked compared to color and flavor. As written by Malcolm Bourne in Food Texture and Viscosity, texture is overlooked based on five different reasons. The first being that texture study is given less importance by the government in terms of funding as compared to blindness that is considered to be a national calamity. Unless the quality of a product is seriously compromised, texture is taken for granted and overlooked. In addition to that, the limited descriptive words for texture are also a reason. For example, some researchers found that a customers' complaint about food taste was perceived as poor flavor; where in actuality the customers were referring to the textural properties of the food (Bourne 2002).

Another aspect to texture being overlooked is that when the texture of a food product isn't right, it is usually brushed off as being poor food quality. On the other hand, if the food has off-odor, off-color, or off-flavor, it is usually an indication of food being unsafe to eat. Lastly, the texture of a product is not something that could be added whenever needed. Change in aroma, color, and taste can be done through a formulation change through the addition of compounds into food (Bourne 2002).

The General Foods Texture Profile parameters perceive texture characteristic in three stages of ingestion – initial, masticatory, and residual (Ranganna 1986). The first 1 to 5 chews of the product is the initial stage of ingestion and that involves the mechanical properties of hardness, brittleness, and viscosity. The next stage is the mastication stage that starts from the initial stage till the time it takes up to swallowing; and this involves gumminess, chewiness, adhesiveness. Lastly, it is the residual stage that includes the previous stages as well as the rate of breakdown, and the general mouthfeel (Ranganna 1986).

There is a wide range of foods and types of textural and rheological properties of food that makes it difficult to classify a product. A better type of classification would be based on the type of test performed. This is so, because different tests are applicable to more than one kind of food. The mastication stage takes place no matter what kind of food product is being consumed. The types of textural tests can be classified into two groups – objective (performed by instruments) and subjective (involves human subjects) (Bourne 2002). The comparison of physical measurement and human perception of texture is as follow:

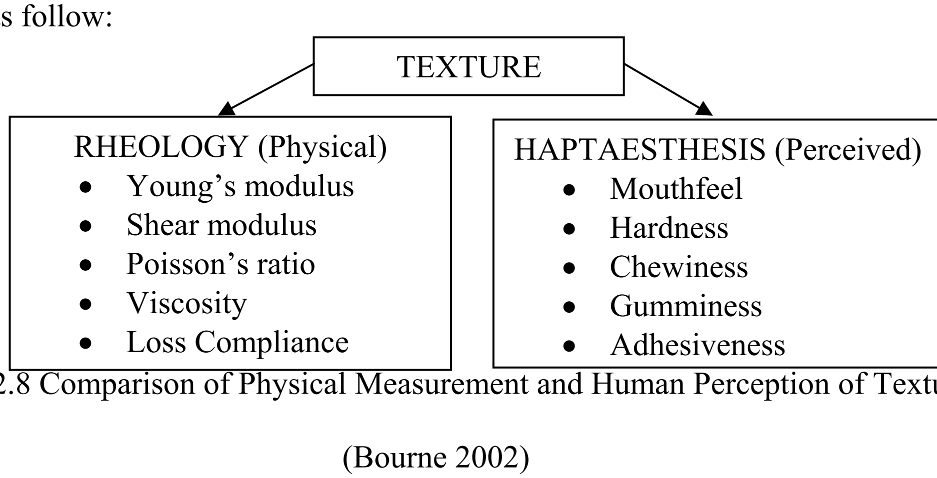


Figure 2.8 Comparison of Physical Measurement and Human Perception of Texture (Bourne 2002)

Rheology is the science of deformation of matter which is the physical approach to measuring texture. Haptaesthesis, on the other hand, is based on the sensory approach (Muller 1973). Texture testing is a quicker and cheaper method for determining the texture of the product compared to sensory by trained panelist (Belie and others 2002). However, measuring texture by instrumental analysis is difficult to correlate to an untrained sensory.

Consumers determine the deformation of fruits and vegetables through the squeezing of product in the hand to determine the firmness. Deformation can be determined through the following formulation:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

Stress is an important characteristic as it is most commonly applied to foods in compression, although it can also be applied in tension or shear (Bourne 2002). Young's Modulus of Elasticity is used to determine deformation of samples. The Young's Modulus of Elasticity is a measure of stiffness and it is the ratio of stress to strain when an elastic solid material is compressed or extended. The slope of the stress-strain curve is Young's Modulus. Young's Modulus equation is as follows (Bourne 2002):

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F / A}{\Delta L / L}$$

E = Young's Modulus

F = applied force that is perpendicular to the area defined by stress

A = cross-sectional area of the sample

L = length or height of the test specimen

ΔL = change in the length resulting from the application of force

Objective measurements involve the use of an instrument. The instrumental methods of texture are based on mechanical tests that determine the resistance of the food to amount of forces applied that is greater than gravity. Generally, the instrument consists of four basic elements, a probe, a driving mechanism, a sensing element, and a read-out system (Kramer and Szczesniak 1973). The force measuring instrument is the most common type of texture measuring instrument. Puncture testing is one of the types of force measuring that pushes a probe into the product to determine the texture (Bourne 2002). The Christel Texturemeter is a hand-operated, multiple-probe instrument that measures the required force to push 25 steel pins through a sample of peas held in a cylinder (Kramer and Szczesniak 1973).

The TA.XT instrument uses as multi-puncture probe (similar to the Christel Texturemeter) which penetrates the product in different parts to create an averaging effect, which is more reproducible. This puncture test includes measuring the firmness. It is difficult to quantify the firmness of a sample such as baby carrots on a piece by piece basis because of the irregular shape and size of each baby carrot. It is easier to test a specific weight or volume of the sample in bulk. In addition to that, the multi-puncture probe is easy to use and has good repeatability as well as differentiation when compared to the Kramer Shear Cell, Ottawa Shear Cell, or the Back Extrusion Rig as shown in the study done by Texture Technologies Corp. to determine the firmness of diced peaches.

Terms that often are correlated to the texture of fruits and vegetables are firmness, crispness, juiciness, and toughness (fibers of the plant tissue). Firmness is one of the attributes that is desired in fresh and minimally processed produce (Lin and Zhao 2007). Firmness can be measured easily and quickly by feeling the product using the hand. However, each time a product is tested using this method, it compromises the true firmness of the product. This is, because the stress caused by the pressure of touching with the hand weakens the tissue thereby shortening the shelf life of the product (Watada 1973).

People often assume that firmness and hardness are the same thing; however, they are slightly different. Firmness is the texture characteristic during mastication that displays moderate resistance to breaking (Bourne 2002). On the other hand, hardness is an attribute of texture that is defined as the resistance to local deformation (Muller 1973). In the 'Analysis of Fruits and Vegetables Products' handbook, Ranganna mentions that hardness is the amount of force needed to compress a substance between the molar teeth (for solids) or between the tongue and palate (for semi-solids) to a given deformation or penetration and designated as soft, firm or hard (Ranganna 1986). The peak force of the 1st compression of the product is the hardness value (Sila and others 2004). Texture quality is often described by the maximum force of the sample, which results from a combined effect of apparent elastic behavior and rupture of the sample (Kidmose and Martens 1999).

Changes in the texture of fruits and vegetables during processing can either be enzymatic or non-enzymatic changes in the cell wall polysaccharide (pectin) (Vu and others 2004). Lee et al. performed a study on the effect of blanching treatments on the firmness of carrots and determined that heat treatments cause changes in pectin solubility, size, and charge density (Lee and others 1979). The two most abundant polysaccharides found in plants are starch and cellulose. Cellulose molecules are contained in cell walls of the plant structure. Pectic substances, hemicelluloses, and lignin are found in the plant cell walls. The lignified cells (inner core of carrots) give the vegetables their woody texture, and do not soften by cooking. Heating of the carrots softens the fibrous tissue and hydrolyzes the pectic substance, which separates the cells (Bennion 1980).

Tissue firmness of carrots experience rapid change in the first few minutes of high processing temperature (>90°C); it then slowly changes over the duration of processing (Greve and others 1994). The beginning of processing and firmness loss is a result of membrane disruption that eliminates turgor (cell pressure) component of texture (Greve and others 1994). Texture of carrots may also be affected by pressure during processing. A study done to compare the effects of high pressurization and cooking on texture and pectic composition of carrots was done and the results obtained showed that high pressurization affected the rupture strain (Kato and others 1997).

The comparison of different processing conditions has been performed to determine the textural degradation of carrots. It was found that carrots that were high pressure/high temperature (HP/HT) processed resulted in a 10-fold slower texture degradation. A combination of HP pretreatment with a calcium soak resulted in the hardest texture (Roeck and others 2010). This study confirms the experiment done by Sila and others in relation to the effects of high-pressure pretreatment and calcium soaking on the texture degradation kinetics of carrots during thermal processing. The rate of thermal softening was retarded during thermal processing due to the high-pressure pretreatments in addition to calcium chloride treatment (Sila and others 2004).

A study conducted by Nguyen and others in relation to evaluating the impact of thermal and pressure treatment in preserving textural quality of selected foods, showed that thermal processing was the worst at retaining texture. On the other hand, pressure-assisted thermal processing better retained texture as well as color (Nguyen and others 2010). When comparing sensory perception and quality attributes of high pressure processed carrots in comparison to raw, sous-vide, and cooked carrots done by Araya and others; results shows that there was a decrease in hardness at day 1 for the sous-vide (29%), pressure treated (44%), and cooked samples (96%) when compared to the raw sample. However, after 14 days of storage the cooked samples did not show a significant increase in hardness compared to the sous-vide and the pressure treated samples (Araya and others 2009).

Basak and Ramaswamy's study showed that carrots that were pressurized at 100MPa in room temperature had a sudden loss in texture value as a result of a pulse action of pressure. It is then followed by a gradual recovery during the pressure hold-time for 1 hour (Basak and Ramaswamy 1998). A similar study showed that heat and pressure treatment changed the texture of carrots within 3 hours of treatment and then changed slowly thereafter. This confirms that softening of the carrots might be due to the long periods of heating (Islam and others 2003).

Color Measurement

Color affects consumers' perception before consumption of the product. Consumers often relate to the phrase 'If it looks good, it is good'. A description of the term color is the sensation that arises from the activity of the retina of the human eye that is attached to the nervous mechanism. When consumers look at a product, light reflects the color of the food to the retina and the sensations are conveyed to the brain; that create the concept of color (Ranganna 1986). The color perception is not only influenced by the chemical and physical properties of colored objects; it is also affected by the composition and quality of light (Wrolstad 2000). The measurement of color allows the expression of the concept perceived by the eyes and brains in terms of numerical dimensions (Ranganna 1986).

The measurement of color is done to determine color change due to oxidation of the pigment which can be caused by oxygen permeating through the package. Color measurement can be performed by a spectrophotometer or a colorimeter. Colorimetry is often based on the determination of the concentration of a substance. This is done through the measurement of the relative absorption of light with respect to a known concentration of the substance (Ranganna 1986). There are three attributes associated with color and they are hue, saturation, and lightness. Hue is the attribute denoted by the kind of color – red, blue, or green. Saturation is the intensity of hue (degree of difference from the achromatic color perception most resembling it) (Ranganna 1986). Lightness is defined as a scale ranging from white to black.

The objective methods of measurement for color includes: spectrophotometers, weighted ordinate method, selected ordinate method, Hunter color and color difference meter, and photovolt reflectance meter. In an effort to define color in absolute terms, the International Commission on Illumination (CIE: *Commission Internationale de l'Eclairage*, 1931) adopted a set of standards. They adopted the standard to allow expression of color in mathematical units which are used to correlate objective measurements to human visual response, standardizing light sources and viewing conditions (Wrolstad 2000). The CIE primaries are red or amber (X), green (Y), and blue (Z); and the relative amounts of them that are required to match a specific color is known to be the "tristimulus" value of the color (Ranganna 1986).

The Hunter system is a tricolorimetric system for measuring food colors. When the tristimulus color filters are combined with selected photocells and a metering circuit, they provide a close approximation of the X, Y, and Z function of the CIE system (Ranganna 1986). Figure 2.9 shows the Hunter color dimensions. L values that are close to the 100 value indicate whiteness; L values that are close to the 0 value indicate blackness. Positive *a* values indicates redness; on the other hand, negative *a* values indicates greenness. The Hunter positive *b* values indicates yellowness; whereas, negative *b* values indicate blueness. It is common to determine the total color difference (ΔE) between a sample and a standard in visual perceptibility units (National Bureau of Standards, NBS units) with the following formula (Ranganna 1986):

$$\Delta E = \sqrt{[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]}$$

Hunter values can be converted into the CIE system if needed or vice versa.

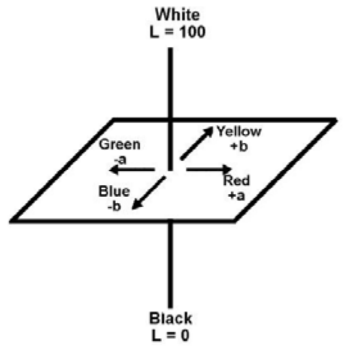


Figure 2.9: Hunter Color Dimensions (Hunterlab.com 2008)

Carrot Carotene Pigments

The color of food is usually due to the natural pigments (chlorophyll, anthocyanins, carotenoids) that are in them (Ranganna 1986). Orange carrots contain beta carotene, with some alpha-carotene, both of which are orange pigments. Carotenoid is a fat-soluble pigment of yellow and orange-red color (Bennion 1980). Carotenoids consist of two structural groups: hydrocarbon carotenes and the oxygenated xanthophylls (Wrolstad 2000). β-carotene theoretically possesses 100% Vitamin A activity thus is considered an important biological compound. Although α-carotene only possesses 50% Vitamin A activity, it is also considered an important compound (Chen and others 1995). These pigments usually found in carrots, are high in Vitamin A, which is predominantly known to contribute to the maintenance of healthy eyes (Simon 2005).

β-carotene (Figure 2.10) is the most common carotenoid found in plant tissues (Fennema 2008). Oxidative destruction, which affects the color intensity of food, is the most common degradative reaction for carotenoids. The oxidation is due to presence of oxygen and the reaction is catalyzed by enzymes (lipoxigenase). In addition to that, oxidation can be accelerated with the presence of metal ions, chemical oxidants, and light. On the other hand, ascorbic acid addition in the food can slow down the oxidation process (Dorantes-Alvarez and Chiralt 2000).

The native state of β-carotene (all *trans* structure), is in a planar conformation (Figure 2.10). The conjugated double bonds, in the *trans* form of β-carotene is responsible for the color intensity (Bennion 1980). Kinks in the molecule are produced in the presence of acid and heat that catalyzes *cis* isomerization, as shown in Figure 2.11 (Wrolstad 2000). When some of the *trans* form of the carotene is changed to the *cis* form, it changes β-carotene to a more pale yellow-orange color. During heating, isomerization from the *cis* to the *trans* form intensifies the yellow color of the fruits and vegetables that originally contains the *cis* form. Oxidation of double bonds in carotenoid pigments causes lightening of color of the product (Bennion 1980).

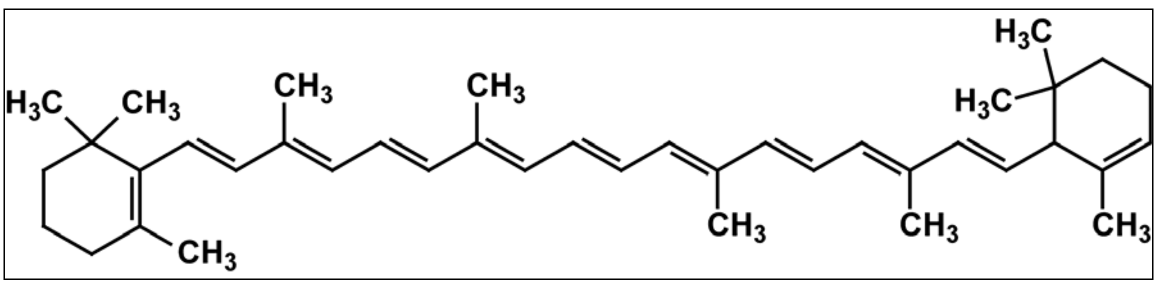


Figure 2.10: *Trans*-Beta Carotene Structure (Schoolworkhelper.net 2011)

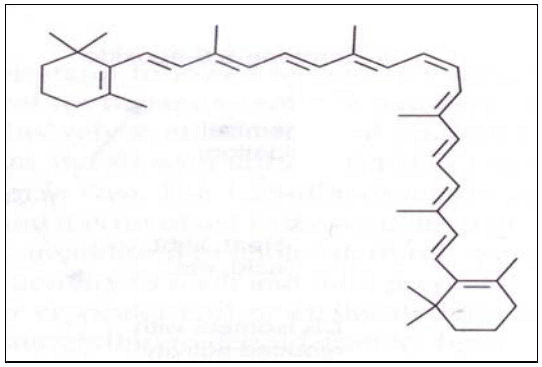


Figure 2.11: *Cis*-Beta Carotene Structure (Fennema 2008)

Degradation of the color of carrots upon thermal treatment was studied by Nguyen and others. There was color change in pressure-assisted thermal processing but it was lower compared to those which were thermally processed (Nguyen and others 2007). Processing of carrot juice indicated that increase in temperature and heating time decreases the yellowness (*b*) and redness (*a*) (Chen and others 1995). A combination of heat with dissolved oxygen is detrimental to strained carrot color as concluded by Talcott and Howard in determining if phenolic autoxidation is responsible for color degradation in processed carrot puree (Talcott and Howard 1999).

The β-carotene content showed a large decline within 3 days after the carrots were minimally processed as shown in the study by Howard and Dewi. The α-, β-, and total carotene levels were reduced after 17 days storage (dry weight basis). The carotene loss during peeling was associated with enzymatic activity or increased exposure to oxygen. Edible coatings used in this study did not affect the carotene level during storage (Howard and Dewi 1996). This and others concluded that light exposure affects the color of carrot stocks (This and others 2008).

Sensory Evaluation

Sensory evaluation is the description or evaluation of a certain product using human subjects. It is the human senses (sight, smell, taste, touch, and hearing) that serve as a tool to determine the quality of the product. According to the Institute of Food Technologists (IFT), sensory science is the scientific method used to evoke, measure, analyze, and interpret reactions to the characteristics of products. These reactions are obtained through the senses of sight, smell, taste, touch, and hearing (IFT Sensory and Consumer Science Division 2011). Statistical analysis is then applied to generate inference or conclusion on consumers' perspective of the products.

Based on the "Handbook of Analysis and Quality Control for Fruit and Vegetables Products", appearance is the main factor that consumers consider when deciding if the product is good. This can be judged by the eye (i.e. color, size, shape, absence of defects, etc.) and it can be the deciding factor of consumers' purchase. The next important attribute that consumers respond to is kinesthetics, which is basically the texture and consistency of the product. Flavor attributes include senses of taste, smell, and feeling; and the sense of taste is limited to the four basic taste of sweet, sour, salty, and bitter. Last but not least is the odor attribute that plays a significant role in the flavor aspect of food product (Ranganna 1986).

Sensory analysis is done to communicate responses of human subjects and partly to provide an input for decision making. Additionally, sensory analysis can answer questions related to product quality, as well as to address questions relating to discrimination, description, or preference (Carpenter and others 2000). It is ideal to correlate instrumental methods to sensory evaluation results.

It is important to plan the study of experimentation in detail before samples are prepared and packed. In order to achieve homogeneity, appropriateness, and randomization to cover the different types of bias that could possibly affect the evaluation of panelist in the study; preliminary study is required (Ranganna 1986). Preliminary studies include screening of the panelist by age, sex, specific likes and dislikes, and availability. Statistical designs can be used to account for variability from week to week among panelist.

Discrimination tests rely on panelists to detect and recognize the differences in the product being studied (Carpenter and others 2000). Discrimination tests include the recognition of primary tastes, difference tests (triangle test, duo-trio test, paired comparison test, ranking test), and scaling methods (scoring and scaling on unstructured scale) (Cooksey 2011). Descriptive tests require trained panelists as this application requires the definition, evaluation, and understanding of the product's sensory characteristics (Carpenter and others 2000). The descriptive tests include Quantitative Descriptive Analysis (QDA), flavor profile, texture profile (Cooksey 2011). Lastly, the preference and acceptability test is aimed to improve on acceptability as well as liking of products (Carpenter and others 2000). The preference and acceptability test is also the affective test that includes paired preference and hedonic scale (Cooksey 2011).

Scaling techniques either are the use of numbers or words to express the intensity of the perceived attribute being tested or a reaction to such attribute. The different types of scaling are category scaling, line scales, and magnitude estimation scaling. Line scales allow panelists to rate the intensity of an attribute by placing a hash mark on a horizontal line that corresponds to the amount of the perceived stimulus. The common line scales are 15cm (6in) with anchors on either ends, or 1/2 in. or 1.25cm from the two ends (Meilgaard and others 2007) as shown in Figure 2.12.

Figure 2.12: Unstructured Line Scale

The hash marks that the panelist places on the line is converted to numbers by manually measuring the position of each mark on each scale using a ruler, a transparent overlay, or a digitizer (direct data entry by stylus on a computer screen) (Meilgaard and others 2007). These numbers are then analyzed to determine the panelist's reaction to the product.

There are factors to consider when designing a sensory evaluation session. Firstly, there should be standardization across the group that all products are subjected to the same type of evaluation under similar conditions. The environment where sessions are run is to be controlled as well. It should be free from any elements such as lighting or aroma, which may distort normal perception. Timing of the research is also important factor when considering a systematic study design. Ideally session should be conducted with the time of day when the product is normally consumed. However, that is usually not possible with panelists' availability. Therefore, it may be better to serve samples at the same time each testing period before meals. The frame of reference aspect should also be noted, whether or not product should have a comparison product to or individually described. Another aspect that is considered is limiting multiple tastings. There should not be too many samples to be tasted. This allows the panelist ability to make accurate distinctions of the product sampled. Lastly, the cleansing of the palate is important as it is essential to remove all traces of flavor that may influence the evaluation of the product (Sokolow 1988).

Careful panel selection and training are necessary to have a well done sensory evaluation. Requirements for panelist selections are: good health, average sensitivity, high degree of personal integrity, intellectual curiosity and interest in sensory evaluation work, ability to concentrate and learn, and availability, as well as, willingness to spend time in evaluation (Ranganna 1986). Upon selection of the panelists and familiarizing them with the product, judging quality should be considered. Judging should be done in individual booths to assure that there will be no communication between panelists.

A multivariate study of the sensory quality and chemical composition in raw carrots was run by Hogstad and others. The sensory analysis performed by panelists in two separate assessments (two separate years) was quantitative descriptive analysis. Attributes were scored on an unstructured scale of 150mm, ranging from low to high (Hogstad and others 1997). Sensory profiling analysis helps develop descriptive terms as well as definitions and methods of assessment. The sensory profiling and consumer “likings” correlated well (Varming and others 2004).

CHAPTER THREE

MATERIALS, METHODS, RESULTS AND DISCUSSION

The objective of this study was to determine if there was an alternative to foil barrier that is microwaveable and still has similar barrier functions for baby carrots. The methodology was to measure the effects of different oxygen barrier materials on the properties of retorted carrots during accelerated shelf life testing. Permeation testing was done to monitor pouch properties. Comparisons of objective measurements (texture and color) to subjective measurements (sensory evaluation) were done based on the different oxygen barrier properties. The four different barrier materials were foil (FOIL), aluminum oxide (AlOx), ethylene vinyl alcohol (EVOH), and nylon (NYLON).

Materials and Methods

Raw Material

Fresh baby carrots (W^{M} Bolthouse Farms, Inc.) from the same use by date (Feb 09, 2011) were purchased from a local grocery store (Ingles, Clemson, SC) the day prior to processing. Salt (Morton Salt, Inc. code date: 07M0AA10) and sugar (Ingles Markets, Inc. code date: 6049-2C3) were also purchased to make a brine solution. The baby carrots were sorted to eliminate defects as well as variability. Variability was determined through visually comparing carrots to a specified sample that was determined in advance to be acceptable. Variability that is acceptable was set to be within ± 0.5cm in length or diameter.

Preparation of Brine Solution

A 1.5% sugar to 0.15% salt solution brine was prepared by combining 600g of sugar and 60g of salt to 80L (176lbs) of distilled water. Salt and sugar were measured using a Mettler Toledo, New Classic SG scale (Model: ML802E/03); whereas the distilled water was measured using an Ohaus DS10 scale, see Appendix A. Brine was prepared the day prior to processing and stored in closed plastic containers.

Preparation of Retort Pouches

Raw materials were obtained from different companies as shown in Table 3.1.

Table 3.1: Materials Types used for Retort Pouch Making

	Company	Material Code
FOIL	All-Foil Inc.	1145-0
AlOx	Toray Plastics Inc.	1011 EG-C2
EVOH	Oracle	EF-CR 1235-0
Nylon	Honeywell	1600 TR
PET	Mitsubishi Plastics Inc.	CTN
CPP	Tredegar Corporation	Extrel 15D
Adhesive	Rohm and Haas	-

*CPP-Cast Polypropylene

*PET-Polyethylene terephthalate

Materials were then laminated together with adhesives using Clemson University Packaging Science Department's laminator, see Appendix B1. PET was first laminated to the barrier layer with adhesive applied on the PET layer. This was then followed by nylon being laminated to the PET/barrier film with the adhesive applied on the nylon layer. Lastly, the PET/barrier/nylon was laminated to CPP with adhesive applied to the nylon.

Pouches were made with the following conditions on the Shanghai Gaoqin Packing Machinary Limited Corporation pouch maker (Model: FSD–600SZ), see Appendix B2.

Table 3.2: Set Point Conditions of the Pouch Maker

	FOIL	AlOx	EVOH	Nylon
Pouch Length (mm)	140	140	140	140
Line Speed (ppm)	25	25	25	25
Set Point Temperature (°C)	145	145	135	135

Packaging of pouches

Baby carrots were packaged in the pouches with a 1:1 ratio w/v of carrots:brine solution. Approximately 100g of carrots were weighed into each pouch using a Mettler Toledo, New Classic SG scale (Model: ML802E/03). A Toyo Jidoki pouch filler/sealer, marketed by Packaging Technologies and Inspection, LLC (Tuckahoe, NY) was then used to fill the prepared brine solution (100mL), see Appendix C. The pouch was then sealed under the following conditions: temperature set-145°C; heating time-1.0sec.; cooling time-1.5sec.

Thermal processing

Prior to processing, two heat penetration (HP) studies were performed. All HP data was collected on the CALPlex Datalogger (SN 701029) running CALSoft 32 software. Ecklund flexible wire thermocouples (TC) were used for all HP testing and were attached to the pouch through the Ecklund C-5.2 stuffing box mounted in a hole in the pouch. Eight pouches with TC fixed to the pouch were filled to a maximum fill weight (~10% above target weight) with an increase in residual gas. All of the TC's were connected to 22 gauge copper-constantan lead wires utilizing Ecklund C-10 male locking connectors. All TC wires were connected through a type T Omega Electric mini-jack to the female connection board of the CALPlex Datalogger, which was connected to a Dell laptop computer through a RS-232 serial connection.

Free leads in the retort were secured with nylon cable ties to the rack close to the TC fitted pouches in the retort racks. One free lead was located at the retort RTD sensor. The data logging system was grounded with a 3-way plug and an additional ground lead wire to the pasteurizer unit. TC scan frequency was set at 30 seconds scan intervals.

From this study, the use of the Ball Formula Method was used to calculate the thermal process that is required to adequately process the baby carrot to reach commercial sterility, F_o=6.

Thermal processing was done in a Surdry Model A-142-OS Retort running in static, water spray mode (Stock America, Raleigh NC), see Appendix D1. The calculated thermal process was for 30 minutes at 250°F after the retort reached the process temperature. Upon completion of processing, the carrots were removed from the retort and air dried on the rack, (see Appendix D2).

Storage Conditions

Retorted baby carrots in pouches were stored in a corrugated box. The boxes are then stored in the walk-in chamber and monitored with the EXTECH® Instrument RHT10 Humidity/Temperature Datalogger. The Q_{10} method was used to determine the predicted shelf life of baby carrots in order to establish the conditions in which to store the baby carrots. This method is based on the theory that the reaction rate doubles for every 10°C change in temperature. Therefore, the predicted shelf life of the baby carrots in retort pouches was determined to be 24.5 weeks. This was determined as follows:

At 23°C, the shelf life of baby carrots in pouches was estimated to be 2 years.

At 33°C, the shelf life of baby carrots in pouches was half the estimated 2 years, 1 year.

At 43°C, the shelf life of baby carrots in pouches was predicted to be 6 months.

Texture Measurement

The texture of the thermally processed baby carrots, defined as the firmness, was measured using a 'TA.XT.plus Texture Analyzer' with 'Texture Exponent 32 version 5,0,6,0 software'. The texture analyzer was equipped with a 50kg load cell and multi-puncture rigs (TA-65), by Texture Technologies Corp. (Scarsdale, NY), see Appendix E1. The force of the texture analyzer is first calibrated using a 2000g weight. It is then followed by the height calibration of the multi-puncture probe to the following conditions: height-120mm; return speed-20mm per second; contact force-10g.

The brine of each pouch was drained and the weight of the baby carrots from each pouch was noted to help in determination of the area/weight calculations. The baby carrots were placed in a plastic cup and compressed based on the target mode of distance that was predetermined to be 119mm. The probes were run at a contact compression rate of 7.0 mm per second, see Appendix E1. The mean value of the compression force of the carrots from eight pouches was given as one single data point.

A preliminary study was run to determine the most suitable attachment to be used in determining the texture of baby carrots. In addition, a comparison of different probe types is available in Appendix E2.

Color Measurement

Upon completion of the texture measurement, baby carrots were randomly selected and color measurements were taken. Color measurements were taken using a Konica Minolta Chroma Meter CR-400, by Minolta Co. Ltd. (Tokyo, Japan), see Appendix F1. The colorimeter was calibrated using the Minolta calibration plate with standards of Y=92.7, x=0.3134, y=0.3192. One baby carrot was selected and mashed with a spatula in a 43mm aluminum pan and color measurements were taken at three different spots using the colorimeter to determine the L*, a*, b* values. Six baby carrot samples were taken and the color measurements were averaged.

A preliminary study was run to determine the inherent variability in the color of the carrots. The preliminary study results are presented in the Appendix F2.

Permeation Measurement

O_2 transmission rates (OTR) were analyzed on MOCON OX-TRAN 2/20 devices (MOCON, Inc. USA), see Appendix G. OTR of the films were measured according to ASTM D 3985. The samples were exposed to 0% RH and tested at 23°C. OTR was obtained for samples prior pre-, and post- processing, and after 14 weeks of accelerated storage.

Sensory – Product Preparation

Double boilers were used to heat up the pouches of baby carrots prior to serving to the panelist. One pouch of baby carrots, including the brine was poured into the pot with three pouches of drained baby carrots. This mixture was heated on an electric stove top. The internal temperatures of the carrots were checked with an OMEGA 871A Digital Thermometer with a unique temperature surface probe, type K, by An OMEGA Group Company (Stamford, CT) to ensure that the internal temperature of the carrots reached 165°C, see Appendix H1. Baby carrots were then dispensed into 3oz. foamed polystyrene cups (two carrots in each cup) with lids, each with pre-labeled randomized codes. The carrots were dispensed approximately 20 minutes prior to arrival of sensory panelist. This was the same treatment for every session.

Sensory – Evaluation

A sensory panel of fourteen volunteers participated in the sensory analysis that was conducted every other week. The sensory panelists underwent three sessions of familiarization training during which they developed and defined descriptive vocabulary of attributes measured. The sensory attributes were then further defined with help of a reference standard. A ballot was created to include the sensory attributes of interest (liking of aroma, liking of color, texture, liking of flavor, strength of aftertaste, liking of aftertaste, and overall liking). The sensory ballot consists of a 15 centimeters unstructured line with anchor words at each end with a descriptive word of the particular attribute, see Appendix H2.

Sensory panelists were informed that the study was a packaging study rather than a product development study. They were also aware that coded samples would be used to limit bias. Panelists were instructed to taste each sample individually and not compare one to the other. For every sensory session, the panelists were required to sign in. Panelists sat at station with four coded foam polystyrene cups with lids containing their samples, a cup of water, an expectorating cup, saltine crackers, fork and napkins, a pencil, and a ballot sheet for each of the coded samples. Each of the ballots was later measured using a centimeter ruler for statistical analysis.

Statistical Analysis

The statistical analysis was performed with the help of Dr. Patrick Gerard using SAS 9.2 software package. The GLM (analysis of variance) test was used to test the hypothesis, and t-test was then applied to determine the significant difference ($p \leq 0.05$) between samples at each time period. Regression analysis was used to study individual treatments over time.

Results and Discussion

Oxygen Transmission Rate of Pouches used for Retorted Carrots

Oxygen transmission rate (OTR) was determined for each retort pouch material pre-, post- processing and after 14 weeks of accelerated storage. Results represent samples taken from 3 pouches of each variable which were tested in duplicate (Table 3.3). The OTR of pouches containing nylon was higher (22.7824 cc/ [m^2-day]) compared to the other materials, with OTR rates less than 1 cc/ [m^2-day] pre-processing. Although the pouches with EVOH barrier did not show as high of an OTR value compared to the nylon, it was higher compared to foil and AlOx pouches. The pouches containing foil and AlOx barrier materials had the lowest OTR and gave similar values before processing.

The average means showed that EVOH (from 0.7090 to 1.0412) and nylon (from 22.7824 to 28.1851) had more changes than AlOx (from 0.2595 to 0.2771). AlOx was the only material that showed slight difference in OTR during storage time.

The foil barrier retort pouch used in the study done by Chandrasekar and others showed that it withstood the processing temperature and pressure (121°C, 28psi). There were no signs of delamination, leakage or spoilage to the white button mushrooms and was acceptable after 12 months of storage at ambient temperature (Chandrasekar and others 2004). In a study by Byun and others in 2010, foil and AlOx retort pouches containing salmon showed better shelf stability compared to cast polypropylene (CPP), which had poor oxygen barrier properties. These results were also confirmed by sensory analysis showing that foil and AlOx had better shelf stability (Byun and others 2010).

Table 3.3: Oxygen Transmission and Permeation Rates

Pre-, Post- Processing, and at 14 weeks of accelerated storage post-processing

Treatment	Oxygen Transmission Rate (OTR), cc/[m^2-day]			Permeation Rate (OTR), cc-mil/[m^2-day]		
	Pre-Processing	Post-Processing	14 Weeks of Accelerated Storage	Pre-Processing	Post-Processing	14 Weeks of Accelerated Storage
Foil	0.2091±0.14	0.1723±0.14	0.1208±0.09	0.9453±0.62	0.7788±0.62	0.5461±0.42
AlOx	0.2595±0.25	0.2771±0.12	0.3639±0.12	1.2456±1.19	1.3302±0.60	1.7467±0.56
EVOH	0.7090±0.75	1.0412±0.13	1.0009±0.04	3.5238±3.75	5.1746±0.65	4.9744±0.21
Nylon	22.7824±4.72	28.1851±0.31	27.8327±1.36	102.9765±21.33	127.3968±1.40	125.8038±6.16

The results of this study indicated that water exposure during retort and high humidity inside the storage chamber affected the barrier properties of EVOH and polyamide (nylon) more so than the other materials. This is because water acts as a plasticizer. Even as the temperature decreased after processing, the EVOH and nylon barrier material did not return to the pre-processing OTR values because the outer layer goes back to its original form thus trapping water in the EVOH and nylon layer. Permeation of EVOH takes place in the amorphous region because EVOH is a semi-crystalline polymer. The water exposure causes EVOH to become plasticized and undergo a reduction in the degree of hydrogen bonding (Axelson-Larsson 1992).

Firmness of Carrots in Pouches with Varying OTR

Carrots retorted in pouches with four different oxygen barrier properties were analyzed for sensory, color, and texture properties. The firmness of carrots was not expected to change regardless of the package's oxygen permeability because oxygen does not affect pectin, which is the main structural component for carrots. Eight pouches were used for each testing period for analysis of texture. Table 3.4 shows the firmness of retorted carrots. Significant differences were seen throughout the study within each packaging treatment except for weeks 8 and 10. Average firmness of the retorted carrots did not change drastically over time, but showed some difference within each week. For example, at week 6, the carrots contained in EVOH were significantly less firm than the carrots in foil and AlOx but similar in firmness to carrots in nylon. The carrots in foil and AlOx barrier pouches were not significantly different from each other throughout the study.

Other attributes of texture (area and area/weight) showed some significant differences between packaging materials at week 0, 2, 6, 12, and 14. Overall, EVOH and nylon showed significant difference at individual time period but the trend is not consistent. This is also confirmed by both texture attributes (area and area/weight) measurements. See Appendix E3. The trends on the graphs representing firmness as seen in Figure 3.1, showed a slight reduction in firmness over time but R^2 values for all measured texture attributes (firmness, area, and area/weight) are low. For example, R^2 values for foil (0.2226), AlOx (0.1525), and EVOH (0.2548) are all below 0.5.

Table 3.4: Objective Measurements of Texture – Firmness (g)

	Time							
Material	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
F	1796.82±298.60 A	1886.19±207.98 A	1692.33±119.05 B A	1694.66±138.86 B A	1732.50±200.19 A	1732.80±197.80 A	1626.61±98.75 B	1777.70±239.65 A
A	1752.94±119.51 B A	1740.33±252.92 B A	1726.99±202.65 A	1810.48±133.15 A	1735.90±201.32 A	1720.75±156.09 A	1801.15±187.78 A	1599.70±175.33 B A
E	1593.42±101.01 B	1657.33±89.73 B	1572.41±117.00 B A	1534.61±124.21 C	1584.20±214.49 A	1580.56±172.20 A	1449.84±120.92 C	1585.00±265.12 B A
N	1781.87±180.54 B A	1608.59±118.55 B	1567.38±149.23 B	1565.43±127.94 B C	1605.50±222.62 A	1547.00±196.58 A	1519.90±180.55 C B	1564.90±118.70 B

* Means in the same column with the same letter are not significantly different

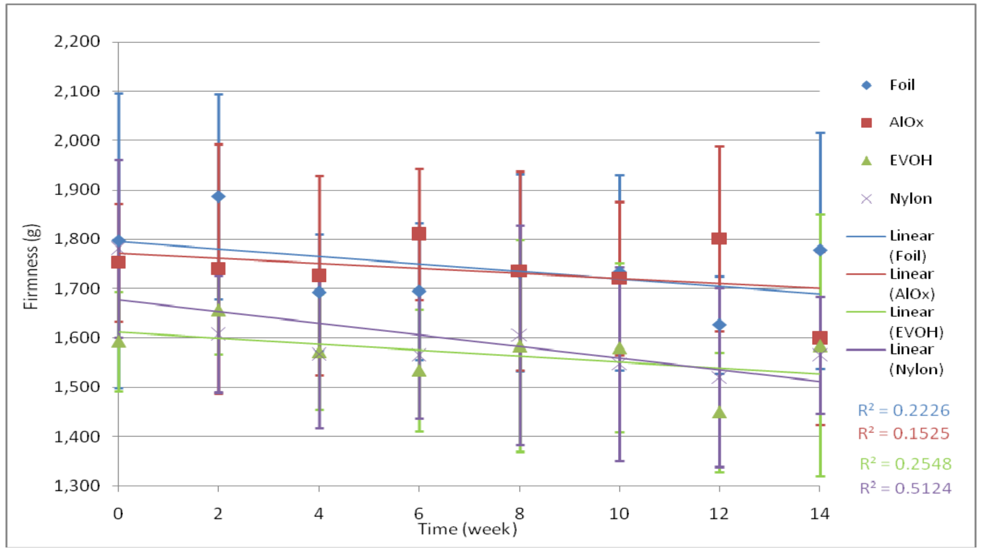


Figure 3.1: Objective Measurements of Firmness

Texture of vegetables softens when heated. Firmness decreases with increasing temperature as demonstrated in the study done by Bourne and Comstock in determining the effect of temperature on firmness of thermally processed fruits and vegetables (Bourne and Comstock 1986). Therefore, the texture would be expected to change only upon thermal processing and not during storage. This is supported by the low R^2 values shown in Figure 3.1. The random statistical difference in firmness by instrumental measurement may be because of the piece-to-piece variability in the carrots. This natural variation from carrot to carrot is the reason to why wide error bar are seen in Figure 3.1 for all materials.

Color of Carrots in Pouches with Varying OTR

Color changes can occur when the food undergoes thermal treatment but more importantly, oxygen can continue to affect the color of carrots after thermal processing. L*, a*, b* values of carrots retorted in pouches with different OTR and stored for 14 weeks of accelerated storage, are shown in Table 3.5, 3.6, and 3.7. L* values indicate the lightness of the product. With a decreasing L* value, it shows that the carrots were getting darker (Table 3.5). The a* values represents the degree of redness in the carrots. A more positive a* value shows that the carrots are redder. The decreasing of a* value shows that the carrots are becoming less red (Table 3.6). Yellowness of the carrot is indicated by the b* value. Decreasing b* value shows that the carrots are becoming less yellow (Table 3.7).

Table 3.5: Objective Measurements of Color – L*

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	50.61±3.28	A	46.27±2.53	A	48.80±3.74	A	45.83±2.66	A	42.94±2.39	A	43.42±1.97	A	43.89±2.80	A	44.36±3.08	A
A	50.20±2.67	A	44.56±3.32	AB	44.88±3.01	B	45.20±1.90	A	42.47±2.25	A	43.21±2.24	A	42.90±1.94	A	44.16±2.01	A
E	49.90±2.81	A	42.86±3.97	BC	43.03±2.36	C	40.40±2.28	B	38.12±2.65	B	37.17±1.73	B	36.30±2.82	B	36.70±2.41	C
N	50.66±3.36	A	41.15±2.09	C	41.05±3.28	D	40.77±2.47	B	37.41±1.99	B	38.15±3.15	B	38.83±2.95	B	40.97±2.06	B

* Means in the same column with the same letter are not significantly different

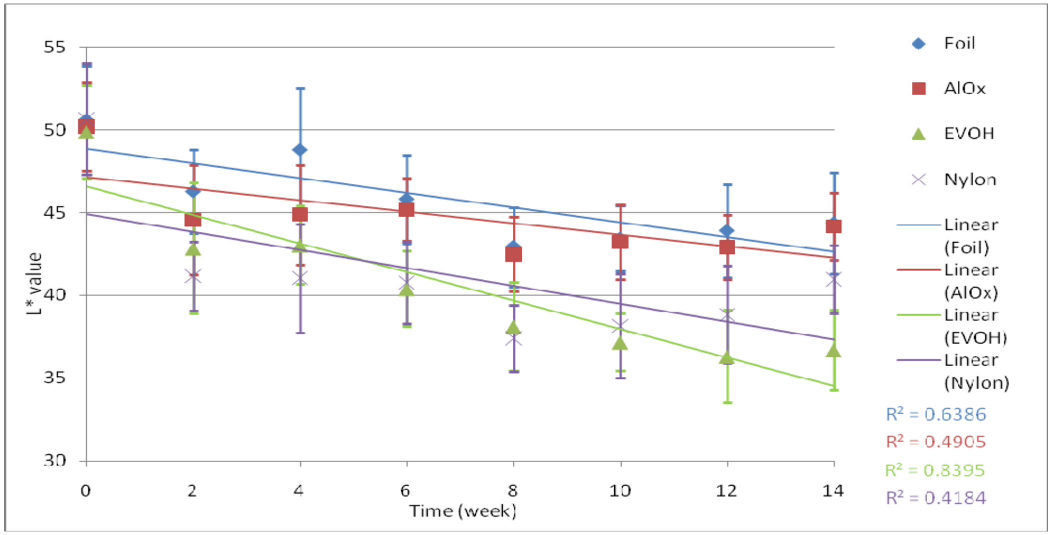


Figure 3.2: Objective Measurements of L* Value

Table 3.6: Objective Measurements of Color – a*

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	21.96±4.02	A	22.62±2.35	A	24.52±2.30	A	23.73±3.01	A	20.73±2.27	A	23.21±2.27	A	20.27±2.50	A	21.24±4.08	A
A	20.46±5.30	A	22.69±2.83	A	19.23±2.39	B	24.07±1.63	A	21.32±2.65	A	21.01±2.43	A	22.97±2.61	A	20.99±2.62	A
E	24.12±3.12	A	21.68±1.66	A	17.99±2.40	B	17.75±1.85	B	14.58±1.83	B	14.83±1.77	B	14.19±1.70	B	15.97±2.20	B
N	22.22±3.21	A	19.22±1.21	B	17.08±2.18	B	16.21±2.74	B	13.48±3.22	B	10.97±2.00	C	8.27±3.32	C	4.49±0.56	C

* Means in the same column with the same letter are not significantly different

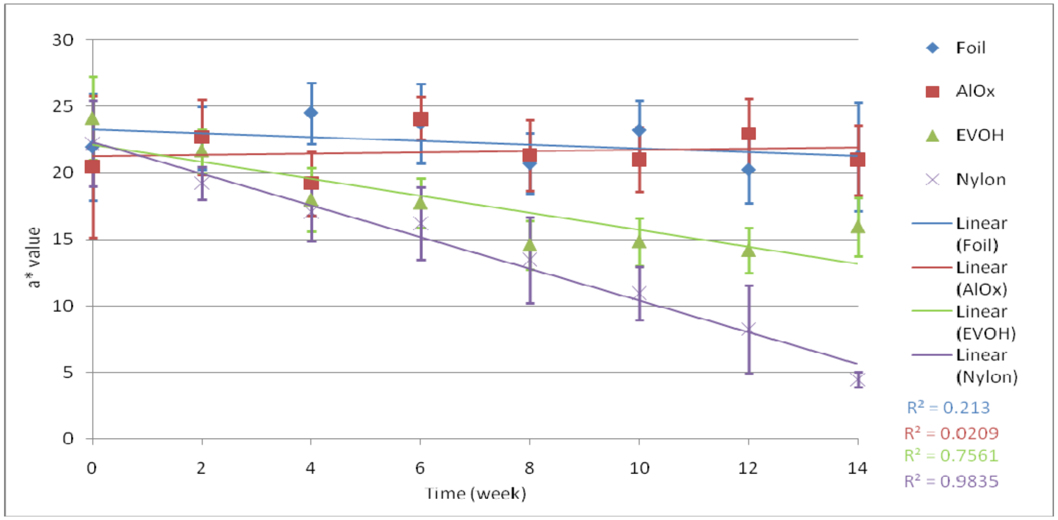


Figure 3.3: Objective Measurement of a* Value

Table 3.7: Objective Measurements of Color – b*

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	51.55±4.73	A	45.74±7.48	A	51.28±9.08	A	47.25±6.33	A	36.92±3.19	A	44.03±6.14	A	37.84±2.42	A	40.88±6.90	BA
A	52.55±7.96	A	43.93±5.79	A	46.03±6.96	AB	40.39±2.93	B	37.12±2.77	A	35.70±2.89	B	39.30±3.14	A	43.53±6.75	A
E	47.60±4.12	A	41.61±8.06	AB	44.09±8.11	B	37.96±7.30	B	29.56±2.45	B	27.28±2.21	C	28.37±2.69	B	35.35±6.79	B
N	52.99±4.69	A	36.64±4.81	B	36.20±5.35	C	32.34±4.07	C	25.69±2.72	C	24.59±4.12	C	23.52±4.97	C	20.32±3.60	C

* Means in the same column with the same letter are not significantly different

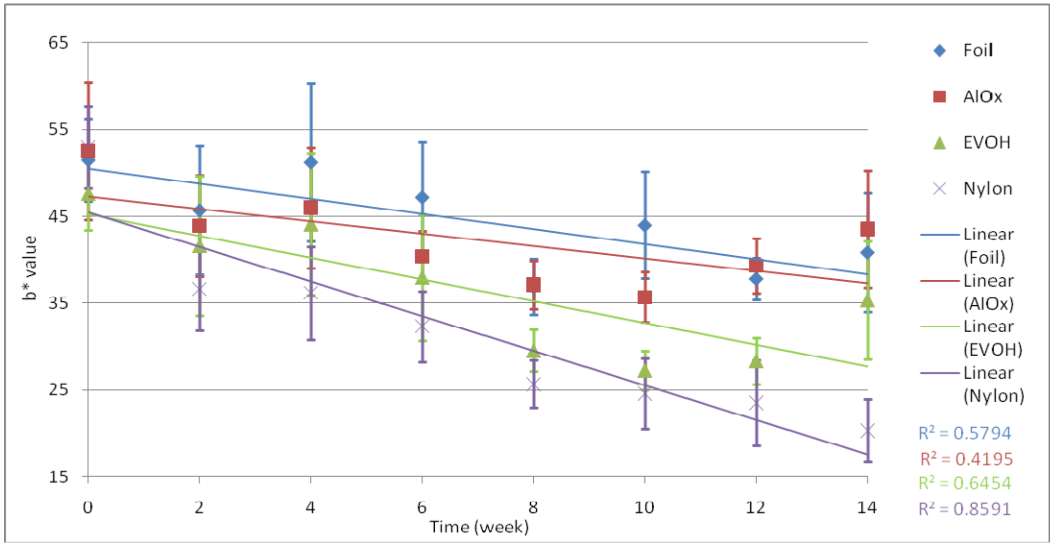


Figure 3.4: Objective Measurement of b* Value

Figure 3.5: Baby carrots at 14 weeks accelerated shelf life

At time 0, there was no significant difference between treatments for all L*, a*, and b* values, as expected. The color of carrots in nylon at week 2 were significantly darker, less red and less yellow compared to all other packaging materials and it remained such throughout the 14 weeks of study. After 6 weeks of accelerated storage, carrots in foil and AlOx pouches were not significantly different for L* and a* value; with some difference with the b* value. The average L* value of foil and AlOx was approximately 45; whereas EVOH and nylon had an average L* value of approximately 40. Average a* value for foil (23.73) and AlOx (24.07) does not show significant difference but is different from EVOH (17.75) and nylon (16.21). Nylon with an average of 32.34 is significantly different from the other materials for b* values. The clear trend of split between foil and AlOx barrier materials with the others was seen starting in week

6. The L*, a*, and b* values for carrots in EVOH and nylon pouches, followed a similar trend but there were no significant differences between carrots stored in these two structures. Overall, carrots in EVOH and nylon were significantly darker, less red, and less yellow than the carrots in foil and AlOx throughout the study after week 4.

Based on Figures 3.2, 3.3, 3.4, and 3.5, EVOH and especially nylon showed trends of decreasing L*, a*, and b* values. The lower R^2 values of color of carrots in foil and AlOx (L*, a*, b*) does not strongly indicate a trend in color. As shown in Figure 3.3, the color value that shows the best fit is a* for carrots in nylon. This is then followed by EVOH. The R^2 value for color of carrots in Figure 3.4 for b* values is not as close of a fit compared to those of the a* values. However, they show a decrease in b* value for carrots in EVOH and nylon. This makes sense because the a* and b* values represents the changes in "redness" and "yellowness" of the carrots, respectively, which is the most concentrated color for carrots on the L*, a*, b* scale.

Carotenoid is sensitive to light exposure, and prone to enzymatic attack (Dorantes-Alvarez and Chiralt 2000). However, the pouches were stored in boxes during the storage period to eliminate the light variable. The carotenoids are stable during heating but are highly sensitive to oxidation. Prior to processing, the carotenoids contained in the carrots are all in the *trans*-form. Upon exposure to heat, *trans*-form slowly shifts to *cis*-form over time causing the color to change to the more pale yellow. Oxidation of double bonds in carotenoid pigments causes the lightening of color of the product (Bennion 1980).

The pigment carotenoid is fat soluble (found in the plastid of the carrots) and is susceptible to oxidation which contributes to the change in color (Charley 1982). Oxygen, in combination with enzymes such as lipoxygenase, oxidizes the carotenoid driving the change in color (Dorantes-Alvarez and Chiralt 2000). The higher OTR of EVOH and nylon allows more oxygen to go through the pouch; thus driving the reaction that changes the color of carrots. Therefore, the carrots of the EVOH and nylon pouches showed significant color change over time compared to foil and AlOx.

Sensory Evaluation of Retorted Carrots in Pouches with Varying OTR

Sensory analysis is used to characterize changes in the carrots in retort pouches of varying oxygen barrier properties stored over time. It can also be used to correlate instrumental measurements to human perception on products. Using a 15cm unstructured scale, 0cm is the lowest score (most undesirable) and 15cm is the highest score (most desirable). Evaluation values that are below 7.5 are tending toward an undesirable score; on the other hand, a score above 7.5 is tending toward a more desirable score. The carrots in nylon pouches were discontinued from the sensory study at week 6, and the carrots in EVOH pouches at week 8, based on sensory scores for color, texture, flavor, and overall liking falling below 4. It was unfair to put the panelist through tasting the carrots that was clearly deteriorating and very undesirable. However, the objective measurements continued until week 14.

At week 0, there were some significant differences between samples for the color attribute. After week 2, differences in oxygen transmission rate between the retort pouch materials had an effect on color of the retorted carrots. Carrots in foil and AlOx were ranked significantly higher compared to carrots in EVOH and nylon pouches. There was a clear difference ($p \leq 0.05$) in color from week 2 to week 6. For example, the average sensory score for liking of color was approximately 8cm for both foil and AlOx; and approximately 2cm for both EVOH and nylon with a separation in liking of color starting week at 4. When nylon was removed from the study, there was significant difference between all three samples that were left, see Table 3.8. At week 10, carrots in EVOH were not tested and there was no significant difference between carrots in foil and AlOx, see Table 3.8 until the end of the study when AlOx was ranked lower in liking of color compared to foil at week 14.

Table 3.8: Subjective Measurement of Liking of Color

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	9.3±2.8	BA	11.5±2.2	A	8.8±4.3	A	9.0±2.5	A	10.8±2.9	A	7.9±4.2	A	6.6±4.0	A	9.5±3.7	A
A	10.6±2.3	A	8.6±4.3	B	8.6±3.9	A	9.2±3.0	A	7.0±2.5	B	6.1±2.6	A	8.3±3.2	A	6.7±3.9	B
E	8.5±3.1	B	4.4±3.9	C	2.4±2.0	B	1.7±1.7	B	1.1±1.0	C						
N	9.2±2.9	BA	3.8±2.9	C	2.1±2.4	B	1.0±1.5	B								

* Means in the same column with the same letter are not significantly different

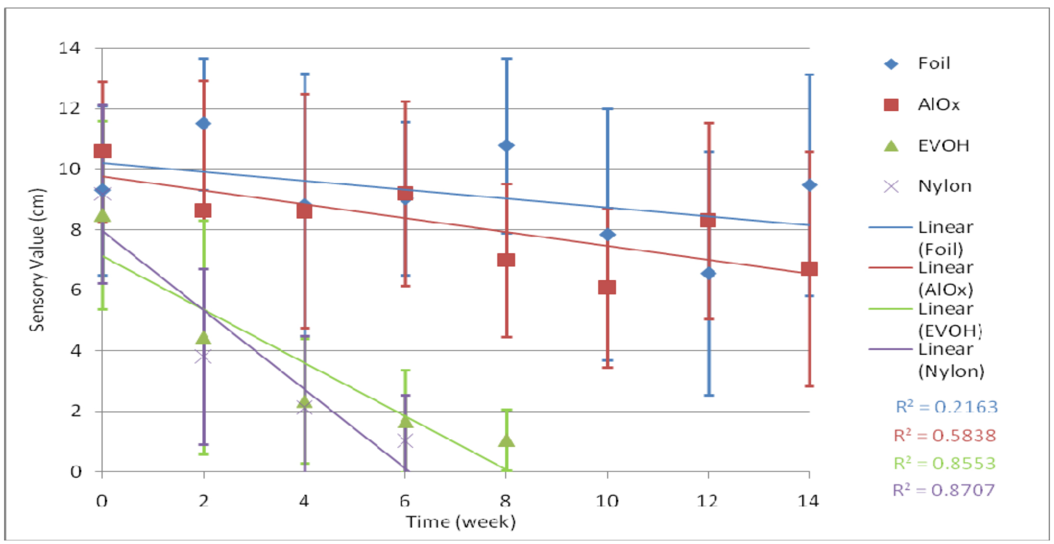


Figure 3.6: Subjective Measurement of Liking of Color

The respective R^2 values of 0.8553 (EVOH) and 0.8707 (nylon), see Figure 3.6, indicate that the panelists were sensing a negative change in the color of carrots over time. However, it is not possible to say the same for the foil and AlOx barrier pouches with lower R^2 values see Figure 3.6. Sensory data for liking of color with R^2 values approximately 0.5 and below for foil and AlOx barrier carrots, indicates that color changes were not changing as much over time as compared to the EVOH and nylon samples.

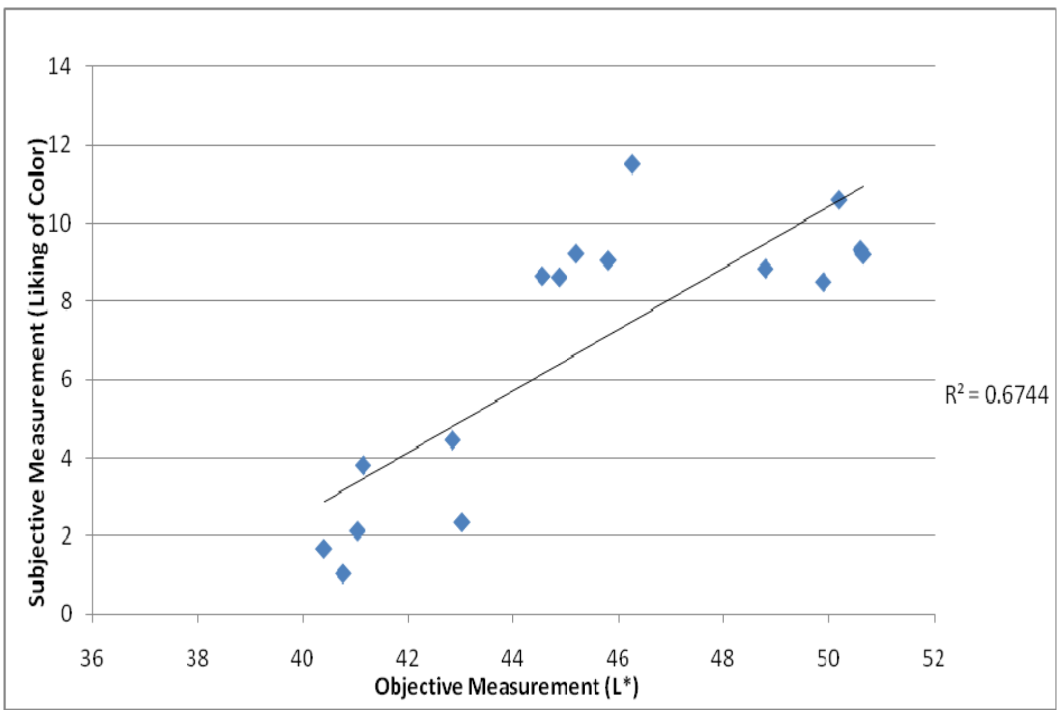


Figure 3.7: Correlation of Objective Measurement (L*) and Subjective Measurement (Liking of Color)

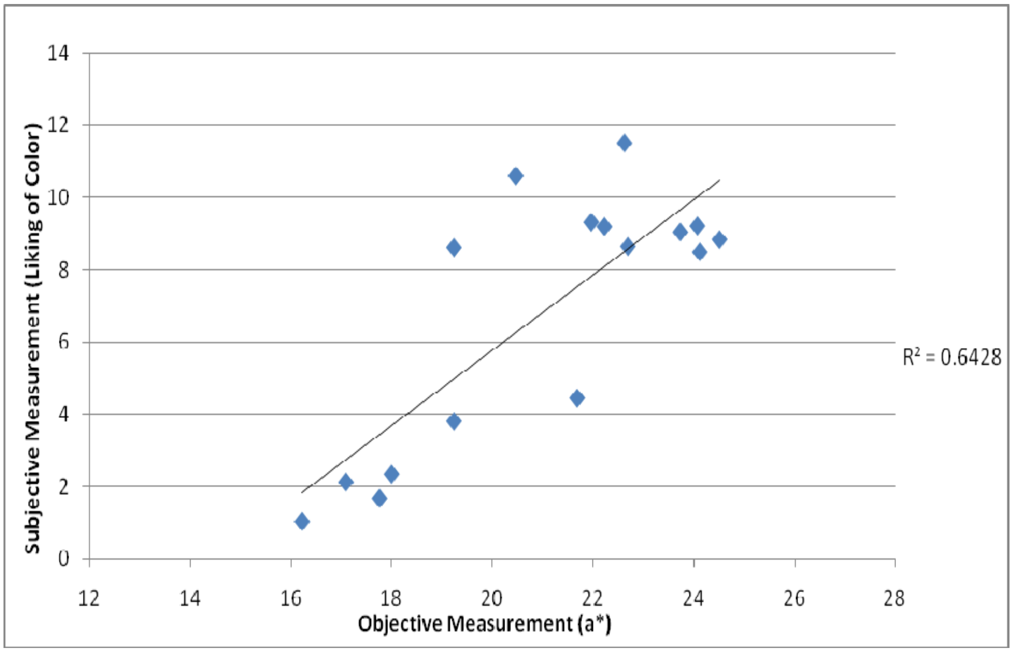


Figure 3.8: Correlation of Objective Measurement (a*) and

Subjective Measurement (Liking of Color)

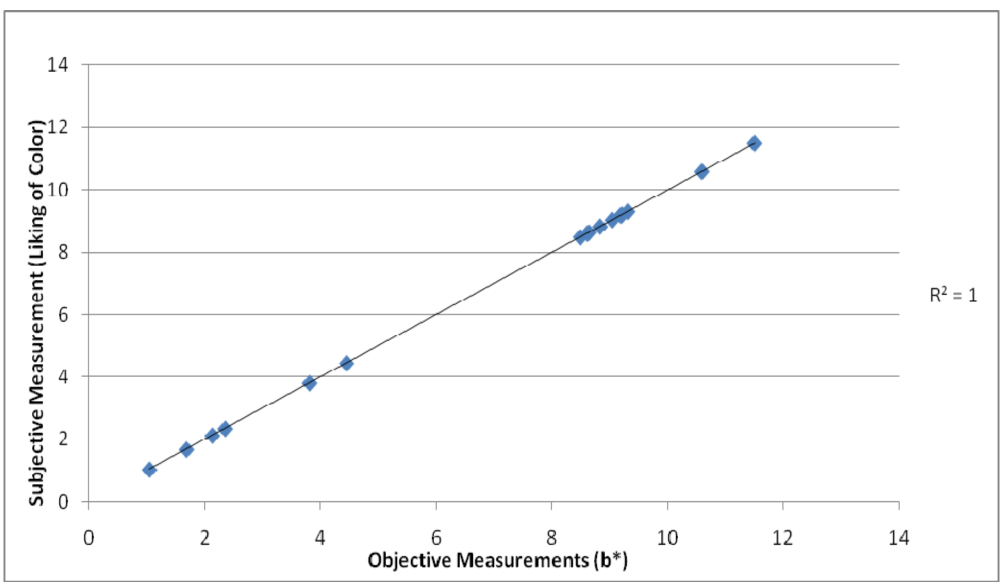


Figure 3.9: Correlation of Objective Measurement (b*) and

Subjective Measurement (Liking of Color)

Correlation of objective vs. subjective measurement was determined; see Figure 3.7, 3.8, 3.9. When correlating objective color measurements with subjective measurements, there was some similarity in R^2 values of 0.6744 for L* value vs. sensory of color liking. The a*'s R^2 value of correlation is 0.6428, showing similar results to the L* correlation.

The objective measurement of b* value vs. liking of color in sensory is a perfect fit with $R^2 = 1$. The b* value indication of yellowness of carrots, was a perfect correlation between the sensory evaluation and objective measurements. This shows that color change that the panelists were detecting was leaning towards the yellowness of the carrots more so than other color attribute (lightness or redness). The data also corresponds to oxidation of the *beta*-carotene structure in baby carrots which causes the pigment to change to a paler yellow appearance, as detected using the colorimeter and human subjects.

Regarding color, the objective measurements are correlated to the sensory results obtained. The correlation is trending in the downward direction. There was not a perfect fit for the regression line of L* and a* and neither were they a strong correlation ($R^2 > 0.9$) to the sensory results due to the fact that objective results were not compared to a specific color attribute of sensory. The close correlation concludes that colors of carrots were significantly deteriorating in the higher OTR pouches.

The sensory evaluation of texture did not show significant differences between carrots in different pouches except for week 2, 4, and 6. Even then there is not a clear trend within treatment of materials at those times, see Table 3.9. Best fit regression line does not fit with R^2 being low for every treatment, see Figure 3.10. The average texture values also show that there is not a clear difference within treatment of materials and all average values were below 7.5cm , indicating that all carrots, regardless of package treatment were considered more mushy than firm. For example, at week 2, the average for foil is 5.8 and that is not significantly different from AlOx (4.9) and EVOH (5.0). The foil and nylon are significantly different at week 2, and not at week 4, and then it is significantly different at week 6. There are not clear trends within treatment.

Table 3.9: Subjective Measurement of Texture

	Time							
Material	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
F	3.8±2.6 A	5.8±3.4 A	5.8±4.0 A	3.6±2.8 BA	3.2±2.9 A	3.3±2.6 A	5.2±4.1 A	5.6±4.2 A
A	3.9±3.0 A	4.9±3.9 BA	5.2±3.8 BA	4.2±3.0 A	3.8±3.0 A	3.2±3.2 A	4.8±3.4 A	4.6±3.8 A
E	3.8±2.4 A	5.0±3.7 BA	2.8±1.9 B	2.6±2.6 BC	3.2±3.3 A			
N	4.3±2.9 A	3.7±2.7 B	5.8±4.6 A	1.6±1.7 C				

* Means in the same column with the same letter are not significantly different

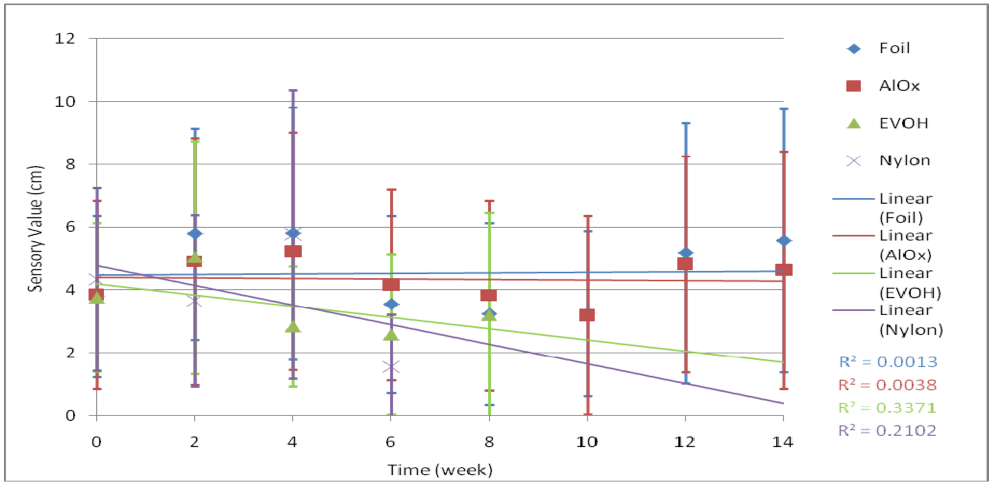


Figure 3.10: Subjective Measurement of Texture

After plotting the objective vs. subjective texture attributes (Figure 3.11), there was no significant difference between them. With an R^2 value of 0.2329, there was no correlation between objective and subjective measurements. One possible cause of this weak correlation could be that panelists were served heated samples whereas objective measurements were tested without heating, straight from the package. Lee and others performed a study on the effect of blanching treatments on the firmness of carrots and determined that heat treatments cause changes in pectin solubility, size, and charge density (Lee and others 1979). Heating of the carrots softens the fibrous tissue and hydrolyzes the pectic substance, which separates the cells (Bennion 1980).

Another reason for poor correlation between sensory evaluation and objective measurement in this study relates to lack of a distinctive trend of texture measured objectively. Although there were individual significant differences, the wide error bar showed a great deal with variability between carrots within treatments. Wide error bars in subjective measurements (Figure 3.10) shows that sensory panelists observed similar difference between carrots within treatments. This relationship indicates that panelists' responses follow a similar trend to instrumental analysis but the data does not show a close correlation because it is difficult to have a good fit when there is wide variability within data sets. Overall, the data indicates that texture was not significantly affected by pouches with different OTR.

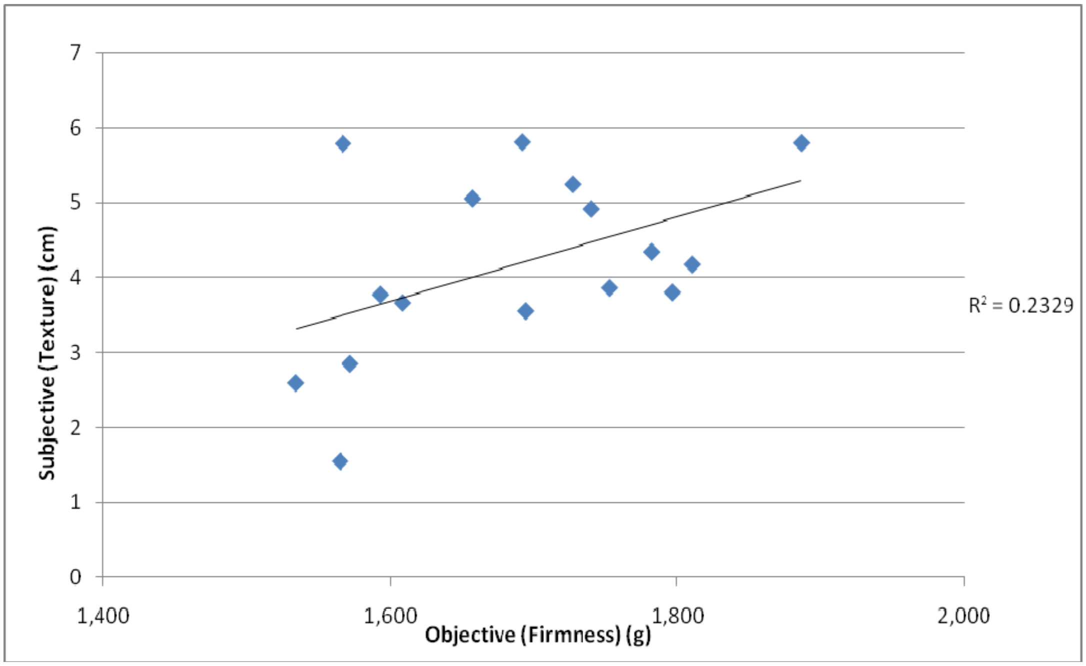


Figure 3.11: Correlation of Objective Measurement (Firmness) and Subjective Measurement (Texture)

Sensory evaluation of flavor showed significant difference at week 2, separating into groups of foil and AlOx vs. EVOH and nylon, see Table 3.10. At week 4, carrots in EVOH were less liked in flavor compared to carrots in foil and AlOx but similarly liked compared to nylon. After that week, the samples were clearly separating out into the significant differences between carrots in foil and AlOx with the EVOH and nylon. Even at week 8, when carrots in nylon were discontinued from the study, carrots in EVOH were less liked (3.8cm) from foil (7.3cm) and AlOx (7.3cm).

As observed in Figure 3.12, the R^2 values of EVOH and nylon (above 0.8) are the two that demonstrate decrease in the flavor attribute. This is not the same for foil and

AlOx with low R^2 values (in the 0.2 range) which indicate that liking of flavor did not decrease over the 14 weeks of storage.

The strength of aftertaste was measured and there were significant differences between carrots contained in pouches with foil and nylon for certain weeks (week 0, 2, 4), more so than the other materials. Mean evaluation sensory scores for strength of aftertaste clearly separated carrots in EVOH and nylon from foil and AlOx (Table 3.11) at week 6, when they were ranked as having a stronger aftertaste. The strength of aftertaste and liking of aftertaste show similar, decreasing trend. The R^2 (0.933) value for carrots contained in nylon pouches confirms that there was an aftertaste which was considered "strong" by the panelist during accelerated storage. The same conclusion can be made for the liking of aftertaste as well for the Nylon sample ($R^2 = 0.8692$), see Figure 3.14.

Table 3.10: Subjective Measurement of Flavor

	Time							
Material	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
F	9.1±2.8 A	9.3±2.2 A	8.8±2.7 A	7.0±3.8 A	7.3±3.2 A	9.1±3.3 A	8.6±2.6 A	7.4±3.4 A
A	8.6±2.7 A	9.1±1.8 A	7.4±2.9 BA	7.7±3.2 A	7.4±4.1 A	5.6±3.3 A	7.5±1.7 A	8.3±3.1 A
E	6.8±2.0 B	7.0±3.4 B	4.9±3.3 C	3.4±2.7 B	3.9±3.2 B			
N	8.5±2.9 A	5.9±3.2 B	6.1±4.4 BC	4.0±4.2 B				

* Means in the same column with the same letter are not significantly different

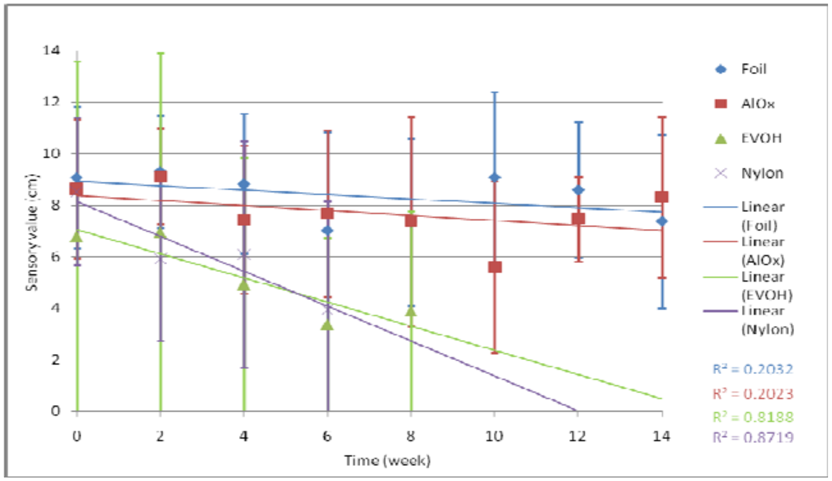


Figure 3.12: Subjective Measurement of Flavor

Table 3.11: Subjective Measurement of Strength of Aftertaste

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	10.4±2.7	BA	11.0±2.5	A	9.5±3.8	BA	10.8±2.6	A	10.5±4.2	A	10.6±3.8	A	10.2±3.3	A	9.7±4.1	A
A	10.6±2.3	A	10.2±2.7	BA	10.1±3.5	A	10.3±3.5	A	10.6±3.5	A	8.6±3.8	A	9.3±4.3	A	9.4±4.0	A
E	8.9±3.2	B	9.6±3.3	BA	7.5±4.4	B	7.0±4.3	B	7.8±4.7	B						
N	9.6±3.0	BA	8.4±3.1	B	8.1±3.9	BA	7.4±3.5	B								

* Means in the same column with the same letter are not significantly different

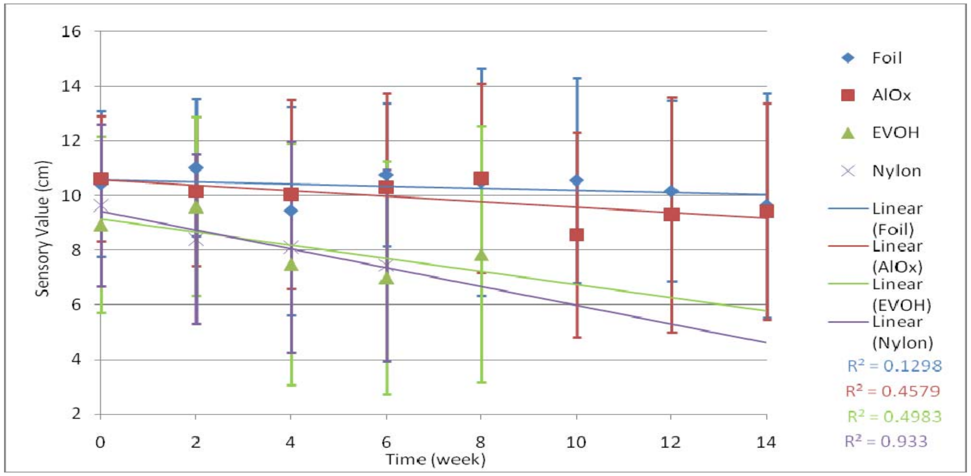


Figure 3.13: Subjective Measurement of Strength of Aftertaste

Table 3.12: Subjective Measurement of Liking of Aftertaste

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	8.9±3.3	A	9.4±3.0	A	9.0±3.0	A	7.6±3.0	A	7.7±3.6	A	8.4±3.5	A	8.2±3.1	A	7.2±3.6	A
A	8.4±1.7	BA	9.0±2.6	A	8.0±3.6	BA	7.4±3.4	A	8.5±2.7	A	6.7±2.7	A	7.4±3.6	A	7.7±3.5	A
E	7.3±2.6	B	7.7±3.6	BA	5.6±3.5	C	4.6±3.0	B	5.1±3.5	B						
N	7.8±3.0	BA	6.3±3.1	B	6.4±3.7	BC	5.3±4.4	B								

* Means in the same column with the same letter are not significantly different

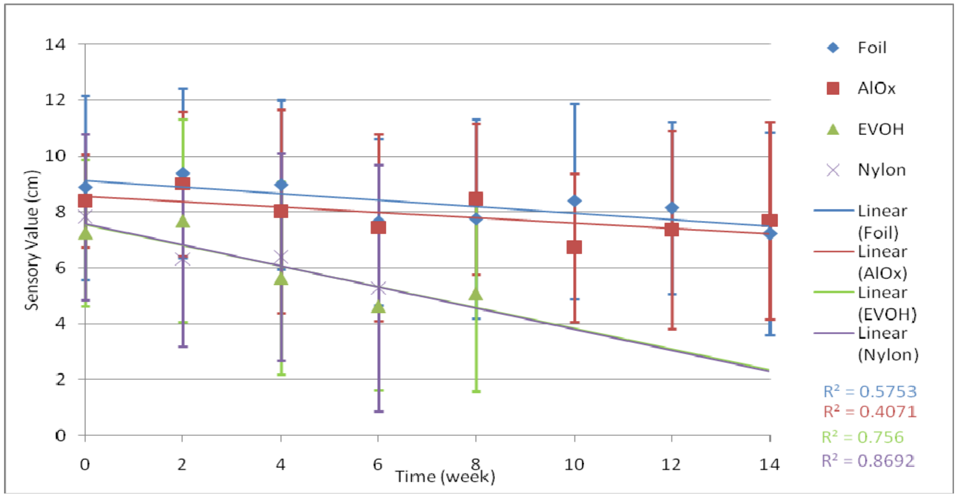


Figure 3.14: Subjective Measurement of Liking of Aftertaste

Carrots in foil and AlOx pouches did not show significant differences within each time period as seen in Table 3.12 for the liking of aftertaste attribute. It is also clear that the regression line, see Figure 3.14, shows that there is no significant change over time. Liking of aftertaste for carrots in EVOH and nylon are similar to the results for strength of aftertaste, at week 6, with the rankings being less desirable compared to foil and AlOx. Carrots in EVOH pouches evaluated for strength of aftertaste is not a good fit with a low R^2 value, thus it cannot be concluded that there is a significant difference over time. However, the liking of aftertaste of carrots in EVOH pouches showed a higher R^2 value (0.756) although still not sufficient to conclude that there are significant differences over time (Figure 3.14).

The carrots showed difference due to the effect of the OTR on pouches through sensory evaluation of aroma. There were significant differences between materials within each testing period except for week 0, 10, 12, and 14 (Table 3.13). From the table, it is obvious that EVOH and nylon are not significantly different. As seen in Figure 3.15, the R^2 value of nylon (0.7999) is the highest among them all. That is the clearest trend in flavor loss over time as determined by panelist's evaluation. It is a weak regression fit for the others ($R^2 \leq 0.1$), thus, not being able to state that flavor is changing over time with low OTR pouches compared to nylon that is high OTR.

Table 3.13: Subjective Measurement of Aroma

	Time							
Material	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
F	8.2±3.1 A	9.8±2.4 A	9.1±2.5 A	8.8±2.5 A	8.0±3.6 B	7.6±3.4 A	9.1±2.5 A	9.7±2.8 A
A	8.3±2.3 A	7.6±3.1 B	9.0±3.8 A	7.8±2.6 BA	9.8±2.2 A	8.0±2.3 A	8.3±3.5 A	9.3±3.1 A
E	6.9±3.0 A	7.9±2.2 BA	8.1±3.8 BA	6.2±2.7 B	7.4±3.6 B			
N	7.9±3.0 A	7.1±3.7 B	6.3±3.5 B	6.5±3.6 B				

* Means in the same column with the same letter are not significantly different

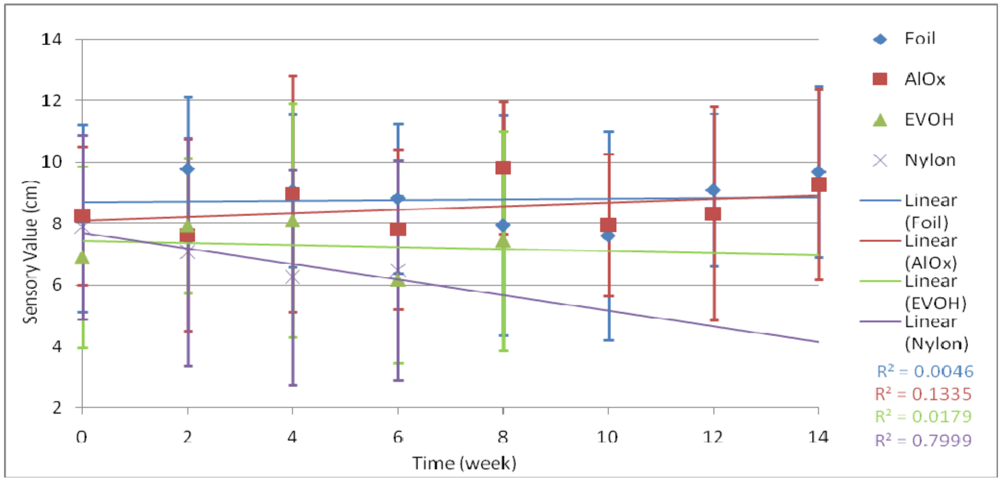


Figure 3.15: Subjective Measurement of Aroma

Table 3.14: Subjective Measurement of Overall Liking

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	9.0±3.1	A	9.8±3.2	A	8.8±3.4	A	7.0±4.0	A	7.1±4.1	A	9.6±3.2	A	8.1±3.7	A	8.1±4.1	A
A	8.7±2.7	BA	8.9±3.4	BA	7.7±3.5	A	7.7±3.3	A	7.5±3.5	A	6.0±2.8	B	7.6±2.9	A	7.9±3.3	A
E	6.8±2.6	B	7.1±4.0	BC	4.0±3.1	B	3.3±2.4	B	3.3±3.3	B						
N	8.5±3.3	BA	5.9±3.2	C	5.3±4.1	B	2.3±2.5	B								

* Means in the same column with the same letter are not significantly different

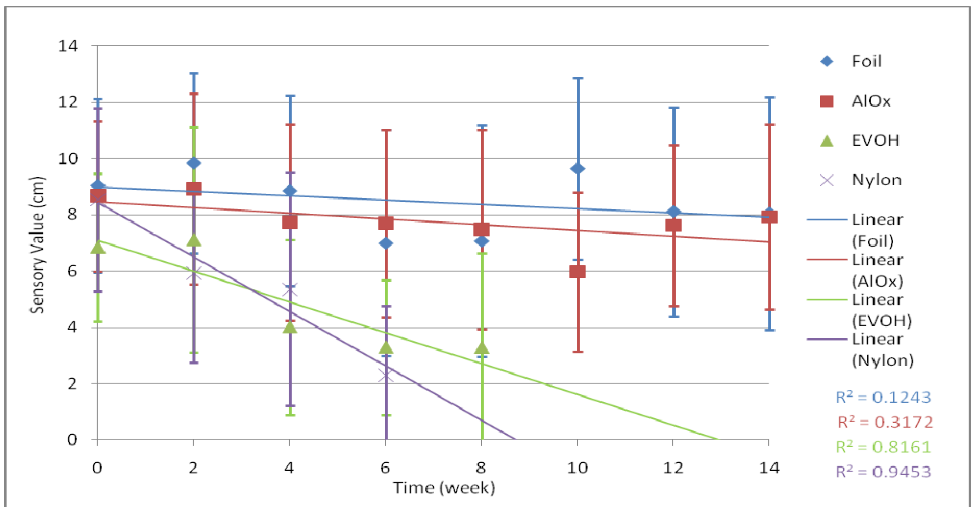


Figure 3.16: Subjective Measurement of Overall Liking

At week 2, carrots in nylon were the least liked of all samples and by week 6 they were ranked as 2.2cm, similar to the carrots in EVOH (3.2cm) (Table 3.14). Carrots in EVOH were ranked significantly lower in overall liking compared to foil and AlOx from week 4 through week 8, when it was eliminated from sensory testing. This is further supported by the regression analysis that shows EVOH and nylon with a higher R^2 value compared to the foil and AlOx (Figure 3.16). With this overall liking attribute tested, it can be concluded that the overall perspective of consumers on retort carrots, is that they would rank carrots in foil and AlOx having more desirable properties than carrots in EVOH and nylon.

Oxygen is one of the most important components that determines the quality and shelf life of foods. Mokwena and others studied the OTR of multilayer EVOH films after microwave sterilization; there was an increase in OTR in the film material after thermal processing. During first 2 month of storage, the multilayer EVOH films recovered to a certain degree and stabilized or increased during 12 months in storage (Mokwena and others 2009).

CHAPTER FOUR

CONCLUSION AND FUTURE STUDY

The higher OTR of EVOH and nylon allows more oxygen to go through the pouch; thus driving the reaction that changes the color of carrots. Therefore, the carrots in EVOH and nylon pouches showed significant color changes over time compared to foil and AlOx. Texture of baby carrots was affected by heat and not oxidation. The natural variability of the carrots may also affect the results observed throughout the study.

Due to the high OTR of EVOH and nylon, the carrots had less liking and acceptability over time. These two barrier pouches did not provide adequate barrier for maximum shelf life when compared to foil and AlOx barrier pouches. The carrots in foil and AlOx had a predicted shelf life of 24.5 weeks or possible more; however, the carrots in EVOH and nylon only lasted half that time.

Future study should focus on the vitamin A content of the baby carrots as determined through β-carotene content. Although color measurement was determined in this study through colorimeter, the determination of β-carotene content is able to further support the fact that color changes is due to the β-carotene (that predominantly controls color of carrots) available in carrots. In addition that that, different barrier materials can also be used in the study to determine if possibly water vapor changes the quality of carrots over time. Another possible study for the future is to conduct study using the same product (ie heated in this case) for instrumental as well and not just sensorial only.

Due to wanting to find an alternative material for microwaving purposes, it would be useful to have results if the product was heated in a microwave throughout the study.

APPENDICES

Appendix A

A1. Mettler Toledo, New Classic SG scale (used for measuring salt, sugar and carrots prior to pouch filling) (Model: ML802E/03).

A2. Ohaus DS scale (used to measure water prior to pouch filling).

Appendix B

Pouch Making

B1. Clemson University Department of Packaging Science's Laminator

B2. Shanghai Gaoqin Packing Machinary Limited Corporation pouch maker

(Model: FSD–600SZ)

Appendix C

Packaging of Baby Carrots

C. Toyo Jidoki pouch filler/sealer

Packaging Technologies and Inspection, LLC (Tuckahoe, NY)

Appendix D

Thermal Processing

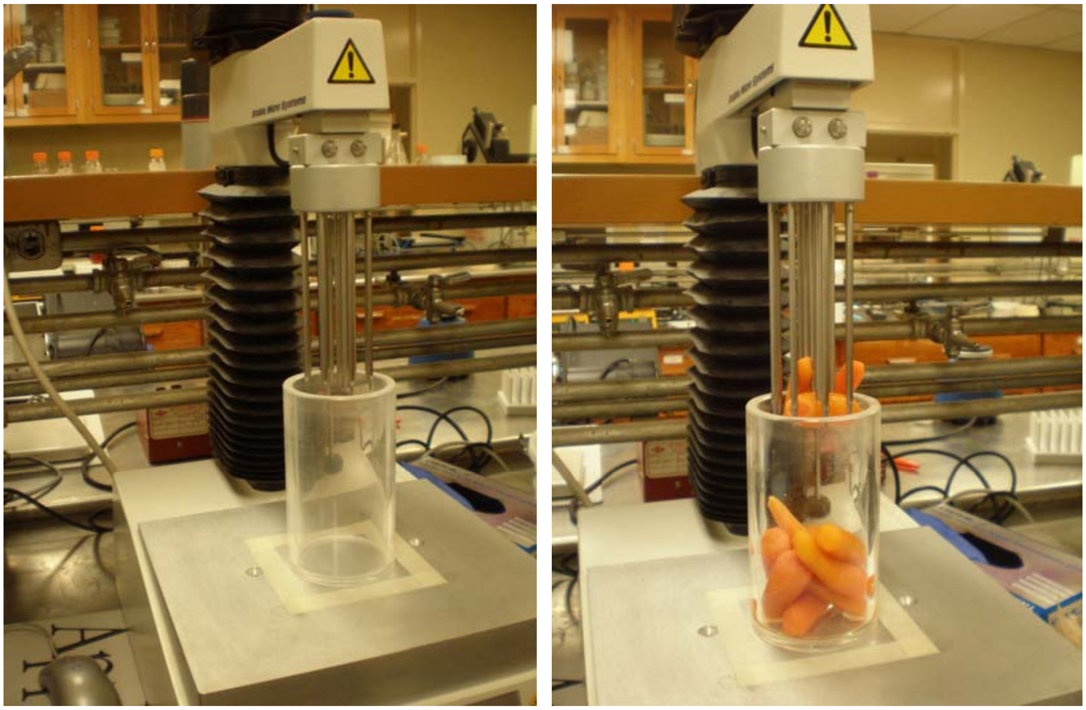
D1. Surdry Stock America Retort

Surdry Stock America Sterilization Systems Division (Raleigh, NC)

D2. Drying of pouches Post-Processing

Appendix E

Texture Measurement



E1. TA.XT.plus Texture Analyzer' and multi-puncture rigs (TA-65)

Texture Technologies Corp. (Scarsdale, NY)

E2. Preliminary Texture Study

Preliminary study was done to determine the sample size to be used in the study in order to account for differences between individual carrots versus treatment differences. Statistical analysis results determined that for texture analysis, n = 8 were sufficient to account for randomization of the carrots to allow for treatment differences. From there, testing was done to determine the best texture probe to use for texture measurement. A result of comparison between different texture probes to use for texture measurement is as follow:

Method	**Chisel**		**Puncture**		**Multi-Probe**	
	60% (Strain)	19mm (Distance)	60% (Strain)	10mm (Distance)	60% (Strain)	119mm (Distance)
Average	3.00	3.64	1.81	1.91	8.34	25.85
Standard Deviation	0.77	0.85	0.45	0.42	1.99	1.76
Coef. of Variation	25.79	23.41	25.04	22.21	23.88	6.81

The multi-puncture probe showed that it was the best probe to use for determination of texture with lowest coefficient of variation. In addition to that, the multi-puncture probe accounts for the multiple puncture through the baby carrots and averages them as a single point of firmness.

Table 3.15: Objective Measurements of Texture – Area (g/sec)

	Time															
Material	**0**		**2**		**4**		**6**		**8**		**10**		**12**		**14**	
F	8820.20±1541.99	A	9167.10±1492.49	A	7930.10±919.43	A	8021.00±906.69	A	8380.90±759.46	A	8156.50±1270.90	A	7988.80±1105.70	B A	8263.30±1649.07	A
A	8444.50±1182.60	B A	8417.10±1589.32	B A	7786.40±1013.53	A	8270.80±1494.87	A	7920.50±1101.93	A	8181.60±967.49	A	8900.20±1428.22	A	7972.00±1082.72	A
E	7412.60±1026.57	B	7431.50±602.67	B	7379.60±870.37	A	6916.10±623.05	B	7575.60±878.82	A	7191.60±954.02	A	6583.00±859.73	C	6605.60±720.29	B
N	8889.00±1048.31	A	7394.80±624.02	B	7609.80±1060.93	A	7378.00±940.91	B A	7913.00±918.42	A	7728.60±1207.43	A	7167.30±1318.86	B C	7305.00±777.04	B A

* Means in the same column with the same letter are not significantly different

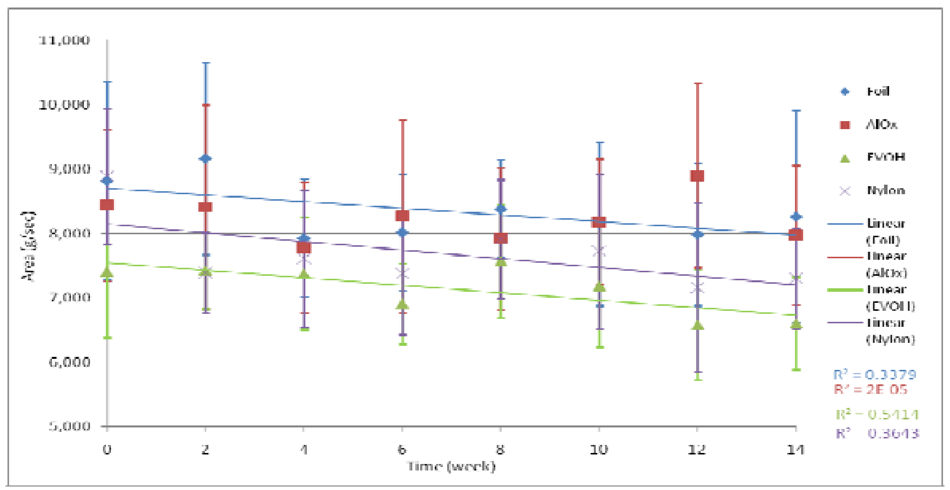


Figure 3.17: Objective Measurement of Area

Table 3.16: Objective Measurements of Texture – Area/Weight

	Time							
Material	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
F	91.33±15.23 A	95.69±16.60 A	82.82±8.24 A	82.66±9.00 A	85.67±8.52 A	83.62±12.65 A	82.69±8.58 B A	87.86±18.24 A
A	85.82±10.78 B A	83.82±15.24 B A	82.83±8.96 A	84.52±11.51 A	83.21±12.61 A	83.74±7.60 A	89.21±13.63 A	81.22±9.33 B A
E	78.49±9.63 B	77.20±5.75 B	75.87±6.71 A	71.94±4.79 B	76.77±8.81 A	74.47±8.67 A	69.11±6.47 C	69.50±6.26 C
N	89.93±9.43 B A	76.98±4.23 B	75.58±9.09 A	76.14±8.05 B A	79.38±7.70 A	77.61±11.34 A	73.21±13.00 B C	74.40±7.88 B C

* Means in the same column with the same letter are not significantly different

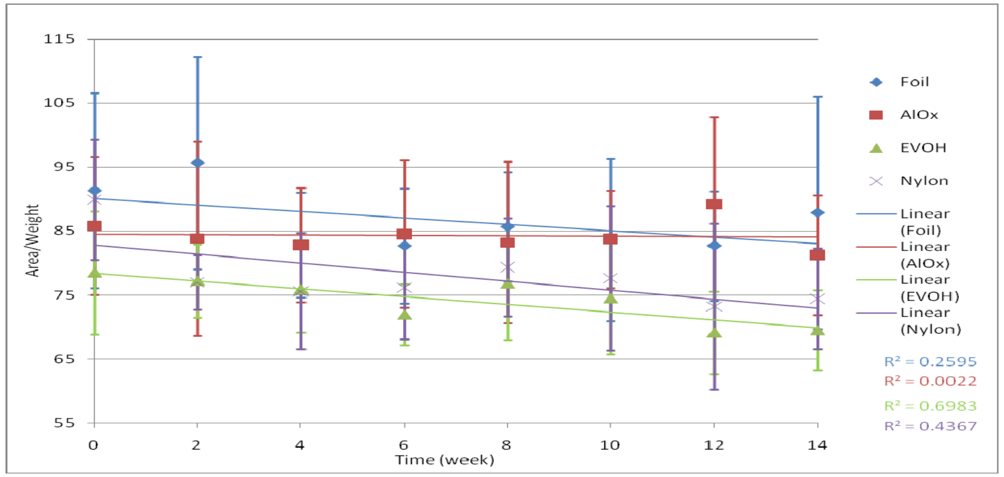


Figure 3.18: Objective Measurement of Area/Weight

Appendix F

Color Measurement

F1. Konica Minolta Chroma Meter CR-400 with Minolta Calibration Plate

Minolta Co. Ltd. (Tokyo, Japan)

F2. Preliminary Color Study

Preliminary study was done to determine the sample size to use in the study in order to account for differences between individual carrots versus treatment differences. Canned carrots were used to run color measurements and 10 samples of carrots were studied. Results were sent to the statistician to determine the number of samples needed to ensure randomization and allow for treatment differences. Statistical analysis results determined that for color analysis, n = 6 were sufficient to account for randomization.

Appendix G

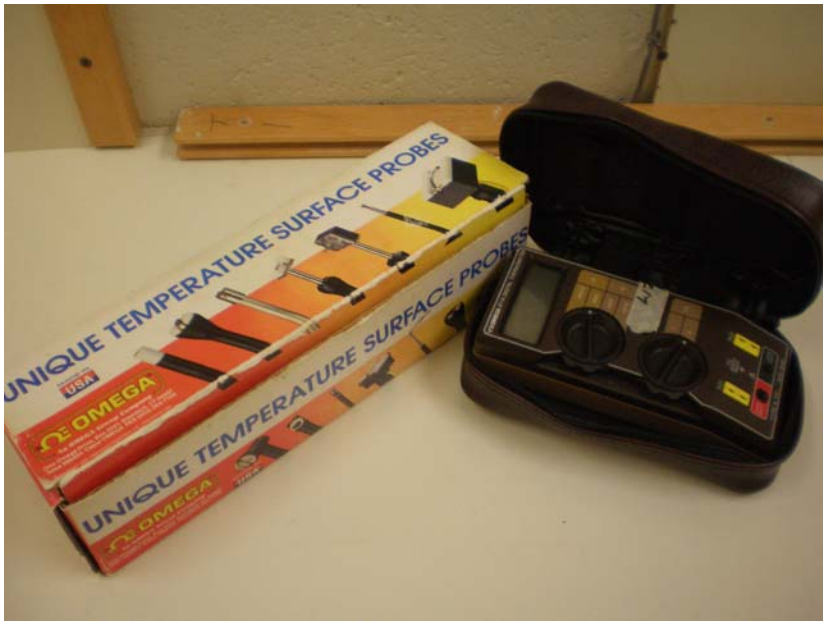
Oxygen Permeation Measurement

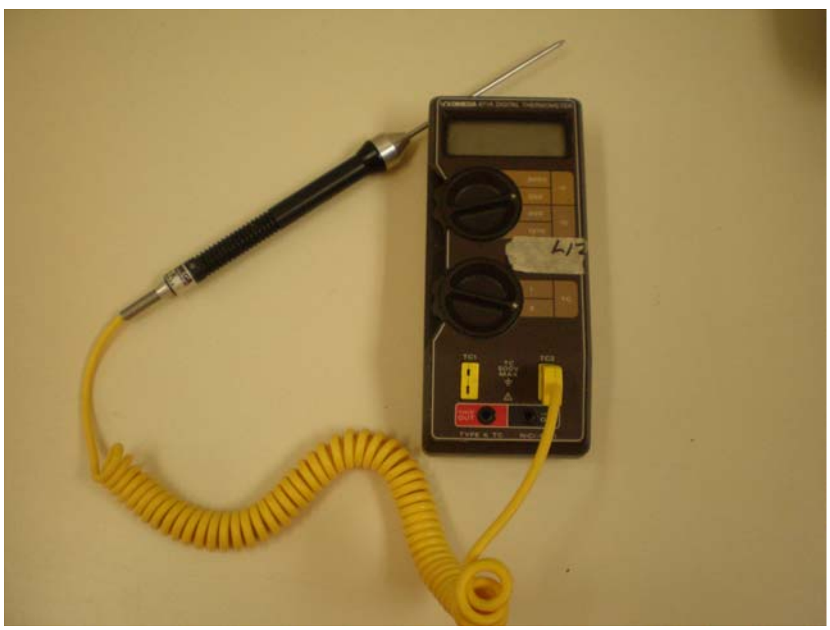
G. MOCON OX-TRAN 2/20 Oxygen Permatran

Mocon, Inc. USA

Appendix H

Sensory Evaluation





H1. OMEGA 871A Digital Thermometer with unique temperature surface probe, type K

An OMEGA Group Company (Stamford, CT)

SENSORY EVALUATION THERMALLY PROCESSED CARROTS

ID No.__________ **DATE: 04-28-11**

Place a hash mark (I) through the line indicating your evaluation of each attribute.
Cleanse your palate with water before you begin and with a cracker between samples.
Evaluate from left to right on your tray.

CODE: 563

Liking of Aroma

Dislike Like

Liking of Color

Dislike Like

Texture

Mushy Firm

Liking of Flavor

Dislike Like

Strength of Aftertaste

Strong Weak

Liking of Aftertaste

Dislike Like

Overall Liking:

Dislike Like

Comments:

H2. Sensory Evaluation Sheet

REFERENCES

Ahmed J, Shivhare US. 2006. Thermal processing of vegetables. In: Sun DW, editor. Thermal food processing new technologies and quality issues. Florida: CRC Press. p 387-422.

Al-Baali AGAG, Farid MM. 2006. Sterilization of food in retort pouches. New York: Springer Science+Business Media, LLC. 205 p.

Araya XIT, Smale N, Zabaras D, Winley E, Forde C, Stewart CM, Mawson AJ. 2009. Sensory perception and quality attributes of high pressure processed carrots In comparison to raw, sous-vide and cooked carrots. Innovative Food Science and Emerging Technologies. 10:420-433.

Aubrey A: Extreme baby carrots: an experiment in marketing [Internet]. Washington: NPR; 2010 [Accessed 2011 April 19]. Available from: http://www.npr.org/templates/story/story.php?storyId=130321785.

Awuah GB, Ramaswamy HS, Economides A. 2007. Thermal processing and quality: principles and overview. Chemical Engineering and Processing. 46:584-602.

Axelson-Larsson L. 1992. Oxygen permeability at high temperatures and relative humidities. Packaging Technology and Science. 5:297-306.

Basak S, Ramaswamy HS. 1998. Effect of high pressure processing on the texture of selected fruits and vegetables. Journal of Texture Studies. 29:587-601.

Belie ND, Laustsen AM, Martens M, Bro R, Baerdemaeker JD. 2002. Use of physico-chemical methods for assessment of sensory changes in carrot texture and sweetness during cooking. Journal of Texture Studies. 33:367-388.

Bennion M. 1980. The science of food. New York: Harper & Row. 598 p.

Beuchat LR, Ryu JH. 1997. Produce handling and processing practices. Emerging Infectious Disease. 3:459-465.

Bindu J, Srinivasa Gopal TK, Unnikrishnan Nair TS. 2004. Ready-to-eat mussel meat processed in retort pouches for the retail and export market. Packaging Technology and Science. 17:113-117.

Bourne MC. 2002. Food texture and viscosity concept and measurement. 2nd ed. London: Academic Press. 427p.

Bourne MC, Comstock SH. 1986. A research note: effect of temperature on firmness of thermally processed fruits and vegetables. Journal of Food Science. 51:531-533.

Brody AL. 2003. The return of the retort pouch. Food Technology. 57:76-79.

Brown WE. 1992. Plastics in food packaging–properties, design, and fabrication. New York: Marcel Dekker, Inc.. 539 p.

Bull MK, Steele RJ, Kelly M, Olivier SA, Chapman B. 2010. Packaging under pressure: effects of high pressure, high temperature processing on the barrier properties of commonly available packaging materials. Innovative Food Science and Emerging Technologies. 11:533-537.

Buzby JC, Lin B, Wells HF, Lucier G, Perez A: Canned fruit and vegetable consumption in the United States, report to congress [Internet]. United States Department of Agriculture, Economic Research Service; 2008 [Accessed 2011 June 3]. Available from: http://www.ers.usda.gov/publications/ap/ap032/ap032.pdf.

Byun YJ, Bae HJ, Cooksey K, Whiteside S. 2010. Comparison of the quality and storage stability of salmon packaged in various retort pouches. Food Science and Technology. 43:551-555.

Caner C, Hernandez RJ, Pascall MA. 2000. Effect of high-pressure processing on the permeance of selected high-barrier laminated films. Packaging Technology and Science. 13:183-195.

Carpenter RP, Lyon DH, Hasdell TA. 2000. Guidelines for sensory analysis in food product development and quality control. 2nd ed. Maryland: Aspen Publishers, Inc.. 210 p.

Carrotmuseum.com: The origin and evolution of baby carrots [Internet]. c1996-2011 [Accessed 2011 April 19]. Available from: http://www.carrotmuseum.co.uk/babycarrot.html.

Chandrasekar V, Srinivasa Gopal TK, Rai RD. 2004. Heat penetration characteristics and shelf-life studies of mushrooms in brine processed in retort pouches. Packaging Technology and Science. 17:213-217.

Charley H. 1982. Vegetables. In: Charley H. Food Science. 2nd ed. New York: Macmillan Publishing Company. p 487-525.

Chen BH, Peng HY, Chen HE. 1995. Changes of carotenoids, Color, and Vitamin A contents during processing of carrot juice. Journal of Agricultural and Food Chemistry. 43:1912-1918.

Code of Federal Regulation: 9 CFR 318.300 – Definitions [Internet]. U.S. Government Printing Office; Jan 2010 [Accessed 2010 July 16]. Available from: http://frwebgate.access.gpo.gov/cgi-bin/get-cfr.cgi.

Cooksey K. 2004. Important factors for selecting food packaging materials based on permeability. Food and Healthcare Packaging Course Notes. 12p.

Cooksey K. 2011. Sensory evaluation laboratory. Food and Healthcare Packaging Course Notes. 13p.

Dorantes-Alvarez L, Chiralt A. 2000. Color of minimally processed fruits and vegetables as affected by some chemical and biochemical changes. In: Alzamora SM, Tapia MS, López-Malo A, editors. Minimally processed fruits and vegetables– fundamental aspects and applications. Maryland: An Aspen Publication. p 111-126.

Flexnews.com: Retort pouch – a fast-growing packaging technology in today's consumer world [Internet]. France: Flexnews – Business News for the Food Industry; 2007 [Accessed 2009 Oct 29]. Available from: http://www.flex-news-food.com/console/PageViewer.aspx?page=12653&str=Retort%20Pouch.

Fennema OR, Damodaran S, Parkin KL. 2008. Food chemistry. 4th ed. Florida: CRC Press. 1144p.

Goff HD: Thermal lethality destruction – thermal destruction of microorgnisms [Internet]. University of Guelph; 2011 [Accessed 2011 June 5]. Available from: http://www.foodsci.uoguelph.ca/dairyedu/TDT.html.

GreenGiantFresh.com: Carrots [Internet]. Salinas, CA: Growers Marketing LLC; 2011 [Accessed 2011 June 4]. Available from: http://www.greengiantfresh.com/carrots.asp.

GreenGiantFresh.com: Green Giant fresh media center [Internet]. Salinas, CA: Growers Marketing LLC; 2011 [Accessed 2011 May 25]. Available from: http://www.greengiantfresh.com/images/carrots/GGF-BabyCutCarrots.jpg.

Greve LC, McArdle RN, Gohlke JR, Labavitch JM. 1994. Impact of heating on carrot firmness: changes in cell wall components. Journal of Agricultural and Food Chemistry. 42:2900-2906.

Greve LC, Shackel KA, Ahmadi H, McArdle RN, Gohlke JR, Labavitch JM. 1994. Impact of heating on carrot firmness: contribution of cellular turgor. Journal of Agricultural and Food Chemistry. 42:2896-2899.

GrimmwayFarms.com: Food safety & organics – baby carrots [Internet]. Bakersfield, CA: Grimmway Farms; 2011 [Accessed 2011 June 3]. Available from: http://www.grimmwaytrade.com/foodSafety/babyCarrots.html.

Halim L, Pascall MA, Lee J, Finnigan B. 2009. Effect of pasteurization, high-pressure processing, and retorting on the barrier properties of nylon 6, nylon 6/ethylene vinyl alcohol, and nylon 6/nanocomposites films. Journal of Food Science. 74:N9-15.

Hirsch A. 1991. Flexible food packaging questions and answers. New York: Van Nostrand Reinhold. 217 p.

Hogstad S, Risvik E, Steinsholt K. 1997. Sensory quality and chemical composition in carrots: a multivariate study. Acta Agriculturae Scandinavica, Section B-Plant Soil Science. 47:253-264.

Holdsworth D, Simpson R. 2008. Thermal processing of packaged foods. 2nd ed. New York: Springer Science+Business Media, LLC. 407 p.

Holovach J. 2009. Innovations in aluminum oxide coating technology launch transparent high-barrier polyester packaging–clear high-barrier PET film advancements open the door to new business. Toray Plastics (America), Inc..

Howard LR, Dewi T. 1996. Minimal processing and edible coating effects on composition and sensory quality of mini-peeled carrots. Journal of Food Science. 61:643-645,651.

Hunterlab.com. Applications notes: Hunter L*, a*, b* color scale [Internet]. Volume 8, No. 9. Reston, VA: Hunter Associates Laboratory, Inc.; 2008 [Accessed 2010 March 12]. Available from: http://www.hunterlab.com/appnotes/an08_96a.pdf.

IFT Sensory and Consumer Sciences Division: What is sensory and consumer sciences? [Internet]. Chicago, IL: Institute of Food Technologists; 2011 [Accessed 2011 Jan 7]. Available from: http://www.ift.org/divisions/sensory/.

Islam MS, Igura N, Shimoda M, Hayakawa I. 2003. Effects of low hydrostatic pressure and moderate heat on texture, pectic substances and color of carrots. European Food Research and Technology. 217:34-38.

Juliano P, Koutchma T, Sui Q, Barbosa-Cánovas GV, Sadler G. 2010. Polymeric-based food packaging for high-pressure processing. Food Eng. Rev.. 2:274-297.

Kato NH, Teramoto A, Fuchigami M. 1997. Pectic substance degradation and texture of carrots as affected by pressurization. Journal of Food Science. 62:359-362.

Kidmose U, Martens HJ. 1999. Changes in texture, microstructure and nutritional quality of carrot slices during blanching and freezing. Journal of the Science of Food and Agriculture. 79:1747-1753.

Kramer A, Szczesniak AS. 1973. Texture measurements of foods. Holland: D. Reidel Publishing Company. 175p.

Lamberti M, Escher F. 2007. Aluminum foil as a food packaging material in comparison with other materials. Food Reviews International. 23:407-433.

Lampi RA. 1980. Retort pouch: the development of a basic packaging concept in today's high technology era. Food Processing Engineering. 4:1-18.

Lange J, Wyser Y. 2003. Recent innovations in barrier technologies for plastic packaging – a review. Packaging Technology and Science. 16:149-158.

Langowski H. 2008. Permeation of gases and condensable substances through monolayer and multilayer structures. In: Piringer OG, Baner AL. Plastic Packaging Interactions with Food and Pharmaceuticals. 2nd ed. Germany: Wiley-VCH. p 297-347.

Lee CY, Bourne MC, Van Buren JP. 1979. Effect of blanching treatments on the firmness of carrots. Journal of Food Science. 44: 615-616.

Lin D, Zhao Y. 2007. Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. Comprehensive Reviews in Food Science and Food Safety. 6:60-75.

López-Rubio A, Hernández-Muñoz P, Gimenez E, Yamamoto T, Gavara R, Lagarón JM. 2005. Gas barrier changes and morphological alterations induced by retorting in ethylene vinyl alcohol-based food packaging structures. Journal of Applied Polymer Science. 96:2192-2202.

Massey LK. 2003. Permeability properties of plastics and elastomers–a guide to packaging and barrier materials. 2nd ed. New York: Plastics Design Library/William Andrew Publishing. 601 p.

May NS. 2001. Retort technology. In: Richardson P, editor. Thermal technologies in food processing. England: Woodhead Publishing Limited. p 7-28.

Meilgaard MC, Civille GV, Carr BT. 2007. Sensory evaluation techniques. 4th ed. Florida: CRC Press. 448 p.

Mermelstein NH. 1978. Retort pouch earns 1978 IFT food technology industrial achievement award. Food Technology. 32: 22-33.

Mermelstein NH. 2001. Military and humanitarian rations. Food Technology. 55:73-75.

Mokwena KK, Tang J, Dunne CP, Yang TCS, Chow E. 2009. Oxygen transmission of multilayer EVOH films after microwave sterilization. Journal of Food Engineering. 92:291-296.

Muller HG. 1973. An introduction to food rheology. London: William Heinemann Ltd. 148p.

Mykytiuk A: Retort flexible packaging: the revolution has begun [Internet]. Deerfield, IL: flexpackmag.com; 2002 [Accessed 2009 Oct 29]. Available from: http://www.idspackaging.com/Common/exhib_11961/Case_File_26.pdf.

Nguyen LT, Rastogi NK, Balasubramaniam VM. 2007. Evaluation of the instrumental quality of pressure-assisted thermally processed carrots. Journal of Food Science. 72:264-270.

Nguyen LT, Tay A, Balasubramaniam VM, Legan JD, Turek EJ, Gupta R. 2010. Evaluating the impact of thermal and pressure treatment in preserving textural quality of selected foods. Food Science and Technology. 43:525-534.

Potter NN, Hotchkiss JH. 1998. Food science. 5th ed. Maryland: An Aspen Publication. 608 p.

Ranganna S. 1986. Handbook of analysis and quality control of fruit and vegetable products. 2nd ed. India: Tata McGraw-Hill Publishing Company Limited. 1112 p.

Roeck AD, Mols J, Duvetter T, Loey AV, Hendrickx M. 2010. Carrot texture degradation kinetics and pectin changes during thermal versus high-pressure/high-temperature processing: a comparative study. Food Chemistry. 120:1104-1112.

Robertson GL. 2006. Food packaging principles and practice. 2nd ed. Florida: CRC Press. 550 p.

Schoolworkhelper.net: Beta-carotene: function and sources [Internet]. SchoolWorkHelper; 2011 [Accessed 2011 June 6]. Available from: http://schoolworkhelper.net/2011/05/beta-carotene-function-sources/.

Selke SEM, Culter JD, Hernandez RJ. 2004. Plastics packaging–properties, processing, applications, and regulations. 2nd ed. Ohio: Hanser Publications. 448 p.

ShopRite.com: Carrots products [Internet]. Glen Burnie, MD: MyWebGrocer LLC; 2011 [Accessed 2011 June 4]. Available from:

http://www.shoprite.com/pd/category/Grocery/Canned-and-Packaged/Vegetables/Carrots/892/.

Sila DN, Smout C, Vu TS, Hendrickx ME. 2004. Effects of high-pressure pretreatment and calcium soaking on the texture degradation kinetics of carrots during thermal processing. Journal of Food Science. 69:205-211.

Simon PW: Carrot facts [Internet]. Madison, WI: USDA Agricultural Research Services; 2004 [Accessed 2011 April 20]. Available from: http://www.ars.usda.gov/research/docs.htm?docid=5231.

Simon PW: Pigment power [Internet]. Madison, WI: USDA Agricultural Research Service; 2005 [Accessed 2011 April 20]. Available from: http://www.ars.usda.gov/Research/docs.htm?docid=5234.

Sokolow H. 1988. Qualitative methods for language development. In: Moskowitz H, editor. Applied sensory analysis of foods. Volume I. Florida: CRC Press. p 3-19.

Stevenson A, Lindberg CA. 2010. New Oxford American dictionary. 3rd ed. New York: Oxford University Press. 2096p.

Strupinsky G, Brody AL. 2011. A twenty-year retrospective on plastics: oxygen barrier packaging materials. 119-140p.

Subramanian V, Srivatsa AN, Nirmala N, Sharma TR. 1986. Performance evaluation of indigenously available packaging materials for retort processing.

Talcott ST, Howard LR. 1999. Phenolic autoxidation is responsible for color degradation in processed carrot puree. Journal of Agricultural and Food Chemistry. 47:2109-2115.

The Aluminum Association Inc.. 2004. Aluminum foil manual. District of Columbia: The Aluminum Association Inc.. 88 p.

This H, Cazor A, Trinh D. 2008. Color evolution of aqueous solutions obtained by thermal processing of carrot (*Daucus carota L.*) Roots: Influence of Light. Journal of Food Science. 73:176-182.

Tucker GS. 2001. Retort technology. In: Richardson P, editor. Thermal technologies in food processing. England: Woodhead Publishing Limited. p 75-90.

Tuomy JM, Young R. 1982. Retort-pouch packaging of muscle foods for the armed forces. Food Technology. 68-70.

UlmaPackaging.com: Baby carrots packaging in vertical machine (vffs) in steady flat bottom pack with 4 edge seal [Internet]. Oñati, Spain: Ulma Group; 2011 [Accessed 2011 May 25]. Available from: http://www.ulmapackaging.com/packaging-solutions/fresh-food-packaging/produce/pepper-carrot-leek/baby-carrots-packaging-in-vertical-machine-vffs-in-steady-flat-bottom-pack-with-4-edge-seal.

USDA: Complete guide to home canning–guide 1 principles of home canning [Internet]. 2011 [Accessed 2011 May 24]. Available from: http://www.uga.edu/nchfp/publications/usda/GUIDE%201%20Home%20Can.pdf

USDA FSIS: Principles of thermal processing [Internet]. May 2005 [Accessed 2009 Oct 17]. Available from: http://www.fsis.usda.gov/PDF/FSRE_SS_3PrinciplesThermal.pdf.

Varming C, Jensen K, Møller S, Brockhoff PB, Chrisiansen T, Edelenbos M, Bjørn GK, Poll L. 2004. Eating quality of raw carrots-correlations between flavour compounds, sensory profiling analysis and consumer liking test. Food Quality and Preference. 15:531-540.

Vu TS, Smout C. Sila DN, LyNguyen B, Van Loey AML, Hendrickx MEG. 2004. Effect of preheating on thermal degradation kinetics of carrot texture. Innovative Food Science and Emerging Technologies. 5:37-44.

Watada AE. 1973. Measuring quality objective and nondestructively. Journal of Food Distribution Research. 23-26.

Weise E: Digging the baby carrots [Internet]. USATODAY.com; 2004 [Accessed 2011 April 19]. Available from: http://www.usatoday.com/life/lifestyle/2004-08-11-baby-carrot_x.htm.

Wrolstad RE. 2000. Colorants. In: Christen GL, Smith JS, editors. Food chemistry: principles and applications. California: Science Technology System. p 215-239.

Zhang Z, Britt IJ, Tung MA. 2001. Permeation of oxygen and water vapor through EVOH films as influenced by relative humidity. Journal of Applied Polymer Science. 82:1866-1872.